Thesis for the degree of Doctor of Philosophy

Saving energy at sea: seafarers' adoption, appropriation and enactment of technologies supporting energy efficiency

Martin Viktorelius

Department of Mechanics and Maritime sciences
Unit for Maritime Human Factors
Chalmers University of Technology
Gothenburg, Sweden, 2020

Saving energy at sea: seafarers' adoption, appropriation and enactment of technologies supporting energy efficiency

MARTIN VIKTORELIUS
ISBN: 978-91-7905-292-8

Series number: 4759

In the series: Doktorsavhandlingar vid Chalmers tekniska högskola. Ny serie.

(ISSN 0346-718X)

Published and distributed by
Department of Mechanics and Maritime sciences
Chalmers University of Technology
SE-412 96, Gothenburg, Sweden
Telephone +46(0)31-772 1000

Cover painting by Beata Viktorelius

Printed by Chalmers Reproservice Gothenburg, Sweden 2020

Saving energy at sea: seafarers' adoption, appropriation and enactment of technologies supporting energy efficiency

Martin Viktorelius

Department of Mechanics and Maritime sciences
Unit for Maritime Human Factors
Chalmers University of Technology

Abstract

The shipping industry is currently facing a major challenge related to environmental sustainability and energy efficiency. New regulations and ambitious international goals that aim at mitigating carbon-based emissions with 50 %, demands on profitability, along with a growing awareness about the climate change, has prompted the maritime sector to increasingly focus on how to improve energy efficiency and reduce fuel consumption in ship operations. This thesis aims at describing and understanding the challenges of improving energy efficiency seen from the lens of crew members' work and to investigate the adoption, appropriation and use of particular technologies, purported to support energy efficiency in ship operation. Using an ethnographic approach and drawing on various practice-based concepts and theories such as communities of practice, activity theory and the imbrication of material and social agency, the four papers (I – IV) included in the thesis were based on extensive field studies in two shipping companies and onboard 11 passenger ferries. The empirical studies revealed that the introduction of new technologies and their subsequent incorporation in and change of established skills and practices is a complex social process depending on the knowing and learning of practitioners as well as their activities, meanings, identities and norms as developed and negotiated in specific settings over time. The thesis contributes to our general understanding of the situated process of adoption, appropriation and use of new technologies in the maritime domain and the sociomaterial nature of energy efficiency.

Keywords: *workplace studies; practice-based; sociomaterial; energy efficiency; shipping; automation; digitalization; energy performance monitoring; ethnography; maritime human factors; seafarer.*

The following papers are included in the thesis:

I. Viktorelius, M., 2018. The Human and Social Dimension of Energy Efficient Ship Operation, in: Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F. (Eds.), Trends and Challenges in Maritime Energy Management. Springer International Publishing, Cham, pp. 341-350.

II. Viktorelius, M., Lundh, M., 2019. Energy efficiency at sea: An activity theoretical perspective on operational energy efficiency in maritime transport. *Energy Research & Social Science* 52, 1-9.

III. Viktorelius, M., 2019. Adoption and use of energy-monitoring technology in ship officers' communities of practice. *Cognition, Technology & Work*, 1-13.

IV. Viktorelius, M., MacKinnon, S. N., Lundh, M. (20XX) Energy efficiency, automation and the imbrication of human and material agency onboard passenger ferries. Submitted to *Journal of human computer interaction studies* (under review)

Table of Contents

Acknowledgments

First, I would like to thank my supervisors Monica Lundh and Scott MacKinnon for giving me the opportunity to write this thesis and for always being there to offer their kind support and encouragement. I am also grateful to all my colleagues at the Maritime Human Factors research group (Katie Aylward, Karl Ydén, Fredrik Forsman, Nicole Almeida Costa, Yemao Man, Sara Eriksson, Steven Mallam, Vitor Fernando Placido da Conceicao and Anders Brödje) for being so friendly and fun. I also want to thank all other researchers and PhD students that I have met at Chalmers and Gothenburg University, especially Ingrid Svensson, Josefin Borg, Hanna Varvne and Karin Andersson. Thank you Barbara Czarniawska and Ulla Eriksson-Zetterquist for letting me visit GRI for a while.

A very special thank you to Hannes von Knorring without whom I could not have written this thesis and to Patrizio Lo Presti for being such a good friend and source of inspiration.

Furthermore, I would like to thank Jenny Palm who was my discussion leader at my Licentiate thesis defense. I would like to thank the PhD thesis opponent Aykut Ölçer and the grading committee with Momoko Kitada, Christer Eldh, Hanna Barbara Rasmussen and Petra Bosch-Sijtsema.

Finally, I also want to thank the Swedish Energy Agency (Energimyndigheten) which funded the first half of my PhD program as well as Stena Line and Styrsöbolaget (especially Ellinor Svensson) for letting me board the ships and all the seafarers that I met during my field studies.

Malmö, April 2020
Martin Viktorelius

Till Kiko

1 Introduction

Shipping is involved in the transportation of over 80 % of all produced goods in the world. With its annual emission of around 1000 million tons of CO_2, maritime transport is a significant contributor to the global environmental footprint. In addition, ship emissions are estimated to increase between 50% and 250% by 2050, due to the expected growth in maritime trade (Smith et al., 2014). This thesis investigates the challenges of improving operational energy efficiency as seen from the perspective of seafarers' knowledge and work and how technologies supporting energy efficiency are adopted and appropriated by crew members onboard ship.

The growing threats posed by global climate change and the amount of carbon-based emissions attributed to shipping, has spurred a recent focus on energy efficiency, advocated as a means for mitigating emissions and improving environmental sustainability in maritime transportation. While already being one of the most energy efficient modes of transportation, many researchers and policy makers still see a need and substantial potential in improving both technical and operational energy efficiency in shipping (Ölçer et al., 2018). In a recent resolution adopted by the International Maritime Organization (IMO) an agreement was made to half the total greenhouse gas (GHG) emissions from international shipping before 2050. An important part of the IMO strategy on the reduction of GHG emissions from ships includes improving energy efficiency of new ships, retrofitting old ships and supporting companies with the development of better energy management practices. In 2013 amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) entered into force requiring new ships to comply with minimum mandatory energy efficiency performance levels, known as the Energy Efficiency Design Index (EEDI). The amendments also required shipping companies to implement technical and operational measures for improving energy efficiency and to develop a Ship Energy Efficiency Management Plan (SEEMP) for each individual ship in the fleet.

Many of the already available technical and operational measures for improving energy efficiency, such as voyage execution, speed optimization, cargo loading, capacity utilization and trim optimization (Bouman et al., 2017), have direct implications for the everyday work of deck officers, ship masters, chief engineers and engine officers. The implementation of many technical and most operational measures depends on how they are adopted by crew members and often presuppose changes or improvements in practices and skills. The role of the ship crew in mitigating emissions and improving energy efficiency has lately been emphasized by several researchers (Baldauf et al., 2018b; Banks et al., 2014; Bertram et al., 1983; Jensen et al., 2018; Kitada and Ölçer, 2015; Lützen et al., 2017; Rasmussen et al., 2018). Bertram et al. (1983, 162) argued, for instance, already almost four decades ago that the "development of crew understanding, motivation, cooperation, and participation" has "the greatest potential for saving fuel". Kitada and Ölçer (2015, 5) suggest, more recently, that the "human element in energy management should be treated as equally important as technology". They argue that while the existing potential for energy efficiency is based on technical calculations and estimations, its realization requires "human intervention in terms of selecting the best measure and implementing it". The selection of measures might, for instance, include activities such as "finding the right trim[1] which gives minimal resistance for the loading condition and service speed", while implementation involves "knowledge and pertinent training for whatever the selected technologies or options are" (Kitada and Ölçer, 2015, 3). Hence, energy efficiency measures, and their estimated potential, are dependent on the social practices of selection, implementation and use.

However, despite the arguments made for the inclusion of the human element in the discourse on energy efficiency there are very few detailed empirical studies examining the work onboard ships in relation to the adoption of new technologies and the development of new skills and practices. A recent review of the general literature on energy efficiency showed that most studies are dedicated to quantitative, technical engineering and economic analyses and only 2,6 % of the included studies are based in social science (Dunlop, 2019). Recent approaches to energy efficiency have urged researchers to include social science in the study of energy use and saving (Sovacool, 2014). In particular, a sociotechnical perspective has been advocated that goes beyond the traditional techno-economic paradigm dominating energy research.

In contrast to the categorical distinction between the technical and human dimensions of energy efficiency, it is argued in this thesis that an adequate understanding of energy efficiency requires an interdisciplinary focus on both the socio-cultural dimension as well as on the material and technological constitution of energy saving practices (Gherardi, 2012; Orlikowski, 2007). This premise is supported by a recent paradigm shift in energy research where neither technological innovation nor peoples' values, behavior and attitudes are thought to determine the transition to more energy efficient systems on its own (Palm and Reindl, 2016). The sociologist Elisabeth Shove wrote a paper in 1998 arguing against the strong conceptual distinction, often made in previous energy research and debate, between the social, on the one hand, and the technical, on the other. Instead, she maintained that energy practices, i.e. all human activities consuming energy, "represents a certain alignment of technical, organizational, and societal aspects" and that technical change is "an unremittingly social, and thus contextual, localized and temporally specific,

[1] The difference of the drafts between forward and aft.

process". Consequently, she argued that "the appropriation or, more accurately, the co-evolution of new technologies takes place against the backdrop of this inter-connecting whole." Organizational change and improvement in energy efficiency should therefore be seen as the result of situated actions and the reciprocal shaping of practices and technologies (Thollander and Palm, 2013).

One important means of improving the operational energy efficiency of ships already in service is, for instance, to install energy performance monitoring tools and other digital and automated technologies onboard ships in order to enable seafarers and managers to learn and develop knowledge about the consumption of energy of particular ships and acquire new practices that save fuel. The use of energy performance monitoring technologies holds promises to mediate the communication between ship and shore and facilitate seafarers' learning of how to operate ships more efficiently given particular conditions (Baldauf et al., 2018b; Poulsen and Johnson, 2016). It also promises to make seafarers more conscious of the consumption of fuel and integrate the concern about emissions into their professional identity, knowing and social practice (Jensen et al., 2018; Lützen et al., 2017). Automated technologies aim, at least in principle, to take over a function or task that was previously performed by a human (Mallam et al., 2019). In theory, automated technologies therefore have the potential of reducing the workload of seafarers and making decisions more optimal and precise (Pazouki et al., 2018).

The technologies investigated in this thesis aim at monitoring and visualizing the energy performance of ships and its subsystems as well as automating parts of the navigational decision making (speed regulation) in order to improve energy efficiency. Technologies supporting onboard work in relation to the execution of energy efficient ship operation have not yet been widely distributed in shipping but have been argued to be crucial in improving operational energy efficiency (Armstrong and Banks, 2015; Baldauf et al., 2018a; Baldauf et al., 2018b; Beşikçi et al., 2016; Lützen et al., 2017; Man et al., 2018a; Man et al., 2020; Poulsen and Johnson, 2016; Poulsen and Sornn-Friese, 2015). While several of the existing maritime studies have investigated current managerial practices related to the implementation of technologies and operational measures for energy efficiency (Johnson et al., 2014; von Knorring, 2019), few studies have examined the implications of the introduction of technologies on the practices and skills of crew members. Little is therefore known about how technologies supporting energy efficiency are integrated with the established practices and goals, what it means for seafarers' professional practice, learning and knowing.

The relationship between new technologies allowing greater access to energy related information and the development of new competencies and work practices is not a straightforward one and there are currently more questions than answers concerning the implementation and use of such and other technologies supporting operational decisions influencing energy efficiency. The implementation of digital tools to monitor and analyze energy performance creates new requirements for the learning and knowing of maritime professionals as the possibility to access real-time and long-term ship performance data can be expected to change the way seafarers accomplish their work and interact with each other. In particular, it is far from evident how attempts to implement new digital technologies and transform traditional practices turn out in actual work environments (outside experimental settings). Nor do we know enough about how seafarers manage to make sense and draw upon the data collected and presented in energy monitoring systems in order to learn how to change their practices. In relation to automated technologies supporting energy efficiency little is known about how the reallocation of functions, from seafarers to computational artefacts, is carried out in practice and, in particular, how automation is adopted by seafarers and what the consequences for their practices, skills and social organization of work are. The work environment of seafarers is already replete with advanced technologies, sources of information, various objectives and demands requiring their full attention and engagement (Ljung and Lützhöft, 2014; Lundh and Rydstedt, 2016; Sellberg, 2017b). It is therefore essential to study the ways seafarers use and learn to use technologies aimed at supporting operational energy efficiency, as their ability to effectively operate and use these new resources will have an impact on the sustainability of shipping and the global environment.

The primary contribution of this thesis can be located to the growing corpus of studies investigating the practices and social processes related to the practical accomplishment of operational energy efficiency in shipping. The thesis' contribution can also be seen as a first attempt to bridge the gap between questions related to the organization and management of energy efficiency in shipping and human adoption of technologies onboard ships. In addition, it also aims at contributing to the current methods and theories used to study and understand the relation between technologies and maritime work more generally.

Research aim and questions

Improvements in energy efficiency can be achieved through the implementation of various known technical and operational measures. However, in order to realize the potential, new technologies and work practices need to be adopted and incorporated into the everyday activities of seafarers. The aim of the thesis is to investigate the work required for improving energy efficiency in ship operations by means of an ethnographic approach examining the adoption and use of technologies onboard ships in two shipping companies. The thesis is focused on the following three research questions:

- RQ 1: What are the challenges of realizing operational energy efficiency as seen from the perspective of seafarers' work and everyday activities onboard ships?

- RQ 2: How are technologies supporting operational energy efficiency adopted onboard ships?

- RQ 3: How do skills, practices and work onboard ships change as a result of introducing technologies and policies supporting operational energy efficiency?

Scope and limitations

Energy efficiency is a multifaceted and complex challenge requiring organizational and technological changes throughout the whole shipping industry. This thesis only investigates a few aspects of this challenge, focusing on the everyday work onboard passenger ships. As a qualitative case study, it aims at exploring social processes and giving *how* answers rather than evaluating outcomes and giving *that* answers. It does not aim at statistical generalization but theoretical and conceptual understanding of the local logic and practicalities of saving energy at sea based on the perspective of particular crews working on the sampled ships.

Structure of the thesis

The next chapter of the thesis reviews the research literature on the organization of energy efficiency in shipping and on the implementation and adoption of technologies in maritime work. Chapter 3 introduces and presents the practice-based theoretical framework used to analyze, conceptualize and discuss the empirical data. Chapter 4 accounts for the methodological choices made and the methods used for this study. Chapter 5 presents and summarizes the empirical findings made in the two case studies (based on the 4 papers included in the thesis). Chapter 6 discusses the results in light of the research questions, previous research and the theoretical framework. Chapter 7 ends the thesis with the conclusions drawn from the studies.

2 Literature review

Service demand, the energy efficiency gap and a paradigm shift in energy research

Energy efficiency is often defined in terms of delivering more services for the same energy input, or the same services for less energy input. As such, it is not necessarily associated with using less energy, but rather with how much energy is used relative to the services demanded (Dunlop, 2019). Improvement in energy efficiency can only be understood in relation to some definition of service. The definition proposed by the IMO, known as the Energy Efficiency Operating Index (EEOI), is expressed as the ratio of mass of CO_2 emitted per unit of transport work, calculated as cargo mass multiplied by the sailed distance (Chi et al., 2018). However, the definition of "service demand" and what should be included in the concept of "useful transportation work", as opposed to wasteful work, is not obvious and depends on values and judgments of the stakeholders in the sector (Patterson, 1996; Pérez-Lombard et al., 2012). In shipping, there is an ongoing debate on the most adequate energy efficiency indicators, and in particular on the most suitable technical proxy for 'transport work' (Zhang et al., 2019). Assessments and comparisons of relative efficiency can only be made if, as noted by Shove (2017) "the meaning of 'service' is captured and standardized" by "foregrounding certain characteristics over others, and fixing these as indicators of service". However, there are certain caveats associated with "carving definitions of both energy and service out of the complex interpenetration of everyday technologies and practices" (Shove, 2017). What gets lost, according to Shove and Walker (2014) is an understanding of the social practices driving demand. The point is captured by Boulding (1981):

> In applying physical concepts like energy to social and economic systems, certain pitfalls have to be avoided, some of which are very easy to fall into. In the first place, it is very important to recognize that all significant efficiency concepts which are based on purely physical inputs and outputs may not be significant in human terms, or at least the significance has to be evaluated. The more output per unit of input the more efficient we suppose it to be. The significance of the efficiency concept, however, depends on the significance of the outputs and inputs in terms of human valuations.

Building on Latours' (1993) notion of purification, describing the attempts of separating nature from culture, Shove (2017) problematize current tendencies in energy research and policy to disentangle, or purify, definitions of energy efficiency from the everyday practices. In order to avoid this, it is important to understand the meaning of transportation work as defined and enacted by practitioners (e.g. seafarers) to better comprehend the concept of service demand and energy efficiency. This thesis is a contribution to this understanding.

Before moving on it should be noted that while the desirableness of the goal of energy efficiency is often taken for granted it has also been problematized in the research literature (Herring, 2006). Research has shown that increases in energy efficiency will not reduce the total amount of emission as long as the shipping sector continues to grow (Bazari and Longva, 2011). Some have even argued that energy efficiency is a misleading concept if emission reduction is the goal since it places to little emphasis on energy conservation (Herring, 2000; Moezzi, 2000; Shove, 2017).

However, from a techno-economic perspective, a substantial potential in limiting emissions form shipping by implementing various energy efficiency measures has been identified (Bouman et al., 2017). Unfortunately, the progress and realization of this potential has generally been considered low (Dewan et al., 2018; Jafarzadeh and Utne, 2014; Rehmatulla and Smith, 2015). The discrepancy between the potential and actual level of energy efficiency, known as the energy efficiency gap, or energy efficiency paradox, has been shown to exist in many sectors of society (Brunke et al., 2014; Jaffe and Stavins, 1994). Various explanations have been given for why energy efficient practices and technologies are not implemented and adopted at the pace expected and needed. Most research and debate on energy efficiency has been based on what Lutzenhiser (2014) characterized as a physical-technical-economic (PTE) model of the world, focusing almost exclusively on devices and costs, with very little consideration of social systems and social actors, often treating them as the "random, noisy, messy, disorganized parts of the world" and excluding them from analysis. In simplified terms, the PTE perspective on energy efficiency is formed by two models often used in energy research: the diffusion and barrier models. The diffusion model claims that the adoption of technologies and practices for saving energy is a top-down process determined by the existence of expert knowledge in a sector and the objective potential of a technology. The barrier model postulates that the potential of available technologies and practices is blocked by various barriers preventing the spread of this knowledge to actors and organizations (Sorrell et al., 2004). Research often starts with ready-made taxonomies of barriers derived from neo-classical and transaction economics which are then tested against the collected data in order to see if a barrier is affecting a sector. Using this method, researcher in shipping have identified a number of barriers thought to inhibit investments in energy efficient technologies and practices. Rehmatulla and Smith (2015) emphasize the existence of both non-market failures (hidden costs and access to capital) and market failures (split incentives); Dewan et al. (2018) highlighted "lack of information of the measures, lack of awareness, lack of competence of ship crews and operation difficulties"; Jafarzadeh and Utne (2014) compiled a list of seven possible barriers explaining the efficiency gap and emphasized inaccuracy of information, incompatibility between technologies and operations, the lack of credibility and trust in the source of information, not using information, not maintaining information, split incentives, and immatureness as the most important barriers to deal with.

Although the conventional techno-economic view is well established in both academia and the policy sphere, also inside the maritime domain, it has received criticism for being overly reductionist, rationalist and relying on a flawed characterization of technology adoption, ignoring the social dynamics of organizational action and change. A major source of critique of the explanation invoking the classical barrier model is that it fails to account for the socio-technical network of energy practices. Lutzenhiser (2014) argues that "the problem is that this perspective [the techno-economic] does not 'work' very well, in that it does not actually provide a useful explanation for energy demands and energy-saving actions" and hence provide little insight into the actual adoption of technologies and practices supposed to improve energy efficiency. The critique originated in the sociological writings of Shove (1998) and Lutzenhiser (1994) but has been developed by them and other researchers since then (Palm and Thollander, 2020). One of the consequences of the reductionist, rationalist and de-contextualized logic of the techno-economic model is, according to Guy and Shove (2000, 64) that it "fails to recognize the routine complexities of energy-related decision- making." What is missing from that approach is, according to Shove, "an appreciation of the social contexts of energy saving action and of the socially situated character of technical knowledge" (1998, 1108).

> Understanding energy is first and foremost a matter of understanding the sets of practice that are enacted, reproduced and transformed in any one society, and of understanding how material arrangements, including forms of energy, constitute dimensions of practice (Shove and Walker, 2014, 48).

Fortunately, the perspective on energy efficiency has recently been broadened by an interdisciplinary agenda emphasizing the sociotechnical context of energy saving actions (Johnson, 2016). In their work devoted to the development of the barrier discourse Thollander and Palm (2013) argued, for instance, that:

> It is important to approach barriers from a new perspective, using non-traditional analytical tools that can contribute new understandings or

> questions as to why a particular barrier is perceived as important in a company. Analyzing a company's culture and existing networks, that is, understanding the context in which energy efficiency goals and measures are discussed, is important in order to take industrial energy efficiency a step further (Palm and Thollander, 2010, 3260).

Thollander and Palm (2013) argue for the application of theories and concepts from social science to understand and bring new light on the energy efficiency gap in different sectors. They suggest, for instance, that such notions as 'communities of practice' (Wenger, 1998) and 'situated action' (Suchman, 2007) can bring out the social, cultural and contextual origins of the traditional barriers identified by the techno-economic approach. Taking a contextual approach involves treating and analyzing barriers not "as simple evidence of intervention failure but as constitutive features of social structure and social action" (Lutzenhiser 2014, 149). The perspective emphasizes the necessity of understanding "the ways in which the social organization of energy-related choices structures opportunities for energy-saving actions" (Guy and Shove, 2000, 66). The limitations of the techno-economic framework suggest that there is a need for other theoretical frameworks and, in particular, "an analysis which instead suggests that technical change is an unremittingly social, and thus contextual, localized and temporally specific, process" (Shove, 1998, 1109). Following John Laws' (1994) 'modest sociology' of technology, Johnson (2016) argues in his dissertation for a research strategy in maritime energy management focusing on the process of organizing, on how barriers are constructed and how work is performed.

Organizing for energy efficiency in shipping

Research on the organization and management of energy efficiency in shipping has utilized both the traditional notion of barriers as well as the more modest approach to account for social action of energy-saving-in-context. Aligned with the sociotechnical perspective, a number of recent empirically driven qualitative studies, investigating practices (rather than barriers) and following actors across organizational boundaries working with ship energy management, have, indeed, shown it to be difficult to isolate a neatly defined set of discrete barriers explaining the energy efficiency gap. Instead it has been demonstrated that the difficulties related to energy efficiency are associated with the *practical organizing* of work with energy efficiency in shipping companies. von Knorring (2019) describe the problem as one where current actions, technologies, routines and institutions condition and constrain the implementation of measures thought to increase energy efficiency. In the absence of sufficiently strong action nets consisting in routines and technologies (cf. Czarniawska, 2014; Leonardi, 2011), bringing about and maintaining change across ship and land organizations is difficult, if not impossible. For instance, Johnson et al. (2014) conducted a case study in two shipping companies following the implementation of an environmental management system with the purpose of improving energy efficiency. A consultant was hired by one of the shipping companies to conduct an energy audit which generated several recommended measures amounting to a substantial expected increase in energy efficiency if implemented. The study revealed problems encountered by the company in the implementation process rooted in a lack of experience of managing projects, unclear division of responsibility, difficulties in the communication between ship and shore as well as insufficient knowledge for how to organize the environmental work. von Knorring (2019) revisited the shipping company three years after the energy audit had been performed and found that few of the recommended procedures, IT systems and communication practices had been implemented due to a plethora of organizational reasons and strategic decisions with unexpected effects. von Knorring (2019) argue that "there was no specific point at which personnel at ShipCo [the shipping company] took the decision to move forward with some suggestions provided in the audit, and not to implement others". Rather, the decisions just 'happened' as a result of organizational priorities and practices. In another study, Dew et al. (2017) investigated the attempts at implementing LED-lamps onboard ships in the US navy and found that the limited rate of adoption was explained by an "inattentive energy culture" in which the needed socially constructed justifications for implementation were not strong enough to convince the decision makers to invest.

Several other studies testify to the organizational difficulties of implementing energy efficiency. Two major themes in the literature on the organization and management of energy in shipping were identified. The first is concerned with how efforts for energy efficiency are coordinated across organizational and professional boundaries and the other theme revolves around the management (collection, interpretation and use) of information (performance monitoring) related to energy consumption.

Cooperation, communication and knowledge sharing between maritime stakeholders

Research has showed that the work to improve ship energy efficiency cannot be reduced to the accomplishment of a single decision maker but depends on the active engagement and collaboration among several professional groups and actors involved in ship operations. The actors with influence on energy efficiency range from individual ship officers (navigators, engineers etc.) to ship yards, shipowners, operators, charterers, cargo owners, ports and traffic management services (Jafarzadeh and Utne, 2014). The development of energy efficient ship operational practices has been described to take several years and require continuous collaboration, trust and knowledge-sharing between crew members onboard ships and managers in shore organizations (Borg and von Knorring, 2019; Johnson and Styhre, 2015). Poulsen and Sornn-Friese (2015, 47) argue that since it generally takes time to change old habits and several years to develop energy efficient practices in a shipping company, a key success factor is "common engagement and continuity in relationships among stakeholders, including crews, ship managers and performance monitoring specialists". Similarly, Hansen et al. (2020) emphasize that successful planning and implementation of measures for improving energy efficiency is dependent on the cooperation of crews and shore managers in order to ensure that the measures are adjusted to fit individual vessels, the working patterns and contractual conditions, and to make the defined goals meaningful to the crew on board. Man et al. (2018a) emphasized inter-departmental (bridge and engine control room) collaboration and the importance of learning and knowledge sharing onboard ships. Energy optimization is described as a coordinated effort, or joint activity, by the two departments. Since the bridge and engine departments consist of practitioners in distinct work communities mutual understanding of each other's tasks and concerns is thought to be critical for coordination.

However, research has showed that the diversity of actors and the divergence of their practices, cultures and concerns, grounded in their different roles and responsibilities, creates boundaries and tensions in interaction which complicates collective efforts of improving energy efficiency. Focusing on the relation between ship crew and onshore management, Poulsen and Sornn-Friese (2015) found that problems in communication and cooperation was a crucial barrier in energy efficient voyage execution. Crews did, for instance rarely get any decision support or guidance on matters of speed, ship trim or onboard power demand, although managers did not think these issues were properly handled by the crews onboard. The lack of communication was conceived as a particularly devastating problem since the outcome of individual fuel saving initiatives can, according to the authors, seldom be properly anticipated a priori. In many cases real world experiments need to be performed onboard ships, and the actual savings can only be properly assessed subsequently. Poulsen and Johnson (2016) argue that "crews and shore employees are far apart, and they meet rarely, if ever. Building trust under such circumstances takes time and effort". Their study highlighted lack of feedback to crews' and problems of trust and knowledge-sharing between crew members onboard ships and managers in shore organizations. Armstrong and Banks (2015) distinguish between operational, technical and commercial stakeholders and describe them as having differing functions, roles and responsibilities and argue that "while effective communications between stakeholders could leverage the strengths of each other, current practices limit their interactions". They illustrate their point with the example of hull maintenance during dry docking and how the lack of a coherent approach, including gaps in responsibilities between the stakeholders, mutually exclusive goals and focus areas as well as differing conceptions of performance monitoring, leads to reactive and minimal maintenance. Consequently, hull cleaning is often made after the deterioration is well established and confirmed rather than as part of proactive planning based on forecasts and projections generated by integrated business processes and systems. Johnson et al. (2014) described a similar paradox related to the nature of energy efficiency in shipping. They found that since the potential for improvement in their case study was divided into many smaller areas in various parts of the organization no one was fully responsible or held accountable for energy use within the companies they studied.

Looking further at the cooperation between, rather than within, maritime organizations also reveals challenges of coordinating collective efforts to improve energy efficiency. Johnson and Styhre (2015) studied unproductive waiting time in ports and the potential for energy efficiency associated with decreased speed and emphasized the large number of actors and stakeholders that need to collaborate and organize their resources and knowledge in order to achieve efficient loading and discharging of cargo from the ships. They argued that the inefficiencies found in their case study could for instance have been reduced by better cooperation and communication between ports, the ship operator, the ship agent, stevedores and crews. Similarly, an ethnographic case study on a multi-actor collaboration project lead by the Swedish shipowners' association was conducted and reported by Borg and von Knorring (2019) and Borg and Yström (2019). The collaboration project aimed at knowledge sharing between companies for increased energy efficiency and included development of a database with energy efficiency measures, a series of workshops to educate onboard personnel in matters related to energy efficiency, and the establishment of a network of energy efficiency experts in the partner organizations, aimed to facilitate knowledge and experience sharing. However, the longitudinal study showed that the database was never finalized and few participants engaged in the workshops and expert networks because of difficulties of engaging people to participate, managing conflicting opinions about collaboration structures and goals as well as problems in concretizing and agreeing on shared visions.

Energy performance monitoring for energy efficiency in shipping

A further prerequisite for the improvement in energy efficiency and the development of energy saving practices is, as reported by several researchers, access to reliable and detailed information on energy consumption, collected over time, and distributed to different actors in and across organizations and departments (Armstrong and Banks, 2015; Jafarzadeh and Utne, 2014; Johnson and Styhre, 2015; Man et al., 2018a; Rony et al., 2019; Schøyen and Bråthen, 2015). It is argued that information is necessary for accurate and timely decisions on investments in energy efficiency measures, the implementation of fuel saving initiatives, during ship operations and to raise awareness about energy consumption among all decision makers at sea and onshore. It is emphasized that in order for energy performance monitoring to be meaningful it needs to be based on real-time data and extensive sub-metering of all energy-consumers throughout a ship to identify and realize cost-effective fuel saving initiatives and adjust practices accordingly (Poulsen and Johnson, 2016).

However, several studies suggest that lack of information is a central barrier in the work of improving energy efficiency (Dewan et al., 2018; Johnson and Andersson, 2014). Based on a large number of interviews with managers in different maritime organizations Poulsen and Johnson (2016) argue, for instance, that many shipping companies lack accumulated real-time data based on sub-metering of the energy performance of their vessels and that this prevents decision makers at sea and onshore from making adequate and prompt changes in ship operations to save fuel and from seeing the effects of their decisions and correct for inefficiencies. This means, according to Poulsen and Sornn-Friese (2015, 47) "that the basis for decision making with the aim of fuel saving remains problematic".

Similarly, Armstrong and Banks (2015) argue that the problem of vessel energy efficiency is related to the current instrumentation and practice onboard and on shore. Today immense data is gathered manually and electronically through numerous logbooks onboard vessel (e.g. the engine room logbook, navigation logbook, cargo logbook, oil record book) as well as numerous systems installed for performance monitoring and electronic data collection. However, fuel consumption is most often measured manually and submitted in a noon report to shore. Utilization of this data for vessel performance analysis and improvement poses a challenge as noon data only consists of aggregated or summative single data points (distance traveled, consumed fuel, weather conditions, etc.). Poulsen and Johnson (2016) argue, that "because ECM [energy consumption monitoring] is only performed once a day, crews and ship managers cannot immediately see the effects of their decisions and correct for inefficiencies".

While the collection of information on energy efficiency measures and ship performance is a necessary component in energy management an equally important aspect of information is how it is used, or as expressed by Johnson et al., (2014, 323) "not only does data need to be gathered; resources need also to be put into analyzing". Hence, energy performance monitoring refers here not only to the collection of information but, more crucially, to the processing and understanding of the data and the distribution of the conclusions to relevant actors. The difficulty is to know what areas to improve, i.e. where most energy efficiency can be gained, and what practices to change and how (Kitada and Ölçer, 2015). von Knorring (2019) describe these difficulties as locally constructing and making sense of the potential for improvement in energy efficiency, i.e. making measures "relevant to actors who are meant to implement them" (von Knorring, 2019, 48).

According to Armstrong and Banks (2015) it is sometimes expected that the staff onboard should "decipher the information or data gathered by the different systems onboard, service providers and shore staff, and then implement optimized operations onboard the vessel". However, the authors continue, "with minimal staff onboard it could be a far stretch to expect integration of information and analysis provided by different systems". Armstrong and Banks (2015) therefore conclude that "there should be an integration of the systems used onboard ships, to allow for analysis and distribution of consistent and not conflicting performance feedback: minimizing the responsibility and burden of integration by staff"

Man et al. (2018a) elaborated on the design requirements of an onboard decision support system for ship energy efficiency and highlighted the informational needs of navigators and engineers during voyage planning, execution and evaluation. They also suggested that the design framework should enable social interaction, learning and the creation of a mutual ground between crew members in bridge and engine departments. Lützen et al. (2017) emphasize that a real time support system has to be meaningful to both the crew and to managers to support the decisions made onboard and ashore. In particular, it has to take the requirements of different stakeholders (authorities and charters) into account as well as the environmental (weather), technical (ship and equipment) and operational (e.g. navigation vs. harbor work) conditions and present "the best option in the given situation".

In summary, the literature reveals a growing interest in the sociotechnical nature of energy efficiency in shipping. Various constraints of improving energy efficiency in the shipping industry related to how work is locally organized and the social and institutional context in which collaboration and interaction takes place, have been described and analyzed. Two important, and interconnected, elements in the work of improving energy efficiency were identified: the development and sharing of knowledge and the availability and interpretation of energy performance data.

However, while most research has focused on the decision making of managers, operators, owners and charterers few studies have focused empirically on the work practices of crew members and on the adoption of technologies and changing of practices onboard ships. Taking a closer look at how technologies are implemented and adopted by seafarers is, however, as suggested by the next section, an important part of understanding the challenges of improving maritime energy efficiency.

The implementation and adoption of new technologies in maritime work

The introduction of new technologies onboard ships is often associated with potential operational and commercial benefits, including increased safety and cost efficiency, more communication and exchange between ship and shore and environmental advantages such as fuel savings, increased productivity, optimized logistical chains and infrastructure (Mallam et al., 2019, 3). However, the introduction of technologies does not automatically lead to adoption, as seen for instance in (Rasmussen et al., 2018) and as emphasized by Jafarzadeh and Utne (2014, 611) arguing that "equipment, such as measurement instruments may be installed onboard ships without being utilized" and that it is a "misconception that the mere installation of equipment saves fuel". One reason for the non-adoption of new technologies in shipping is the lack of crew involvement and engagement in the decision making and implementation process. Bhardwaj et al. (2019) argue that crew members are rarely engaged in the implementation process of new technologies and describe the current practice as one where technologies are typically brought in when ships are in for routine maintenance forcing seafarers to learn how to operate the equipment quickly and adapt to it. Consequently, crews sometimes lack the time and resources to learn how to use new technologies. Sampson and Tang (2015) showed that officers in the shipping industry are often not adequately trained in relation to new on-board equipment. In another survey study investigating deck and engine officers' perception on how to increase the usefulness of technology onboard ships, a majority (72 %) answered that "better training of crew in terms of how to use ship technology" was the most important measure (Allen, 2009).

Learning and work integration

Tang and Sampson (2017) recognize that effective learning in relation to technology can take many different forms, including classroom training, on the job training, and peer mentoring and coaching. Since the design of ships and shipboard equipment rarely is standardized, seafarers often need to "relearn or refamiliarize" themselves with the particular technologies on the different ships they join during their career. Not all new technologies installed onboard are part of the core practices of deck and engine officers, such as RADAR or the electronic chart display and information system (ECDIS), but are rather additional or supplementary decision support tools that shipping companies or owners can decide to take onboard. This is particularly the case with technologies supporting energy efficiency. Because of the proliferation of new digital tools that are not included in the core training of cadets, workplace learning is therefore inevitable. Since the adoption and use of many new maritime technologies often require changing practices and patterns of social interaction (e.g. between ship departments or between ship and shore) it can also be seen as a collective learning process. The things to be learned are not exhausted by the technical specifications of new technologies, but also involve developing new tacit knowledge and embodied skills used in everyday work. Classroom training is thus not always feasible for covering all the problems that may crop up in the on-going use of new technologies but require crew members to engage in other forms of informal learning processes, such as consulting colleagues or technical experts, in order to solve those problems. The success of formal or informal training to use new tool is also, as emphasized by Tang and Sampson (2017) dependent on seafarers motivation, which they recognize to be dependent on the social world in which learning takes place.

Furthermore, it should be acknowledged that even if the introduction of new technologies lead to their utilization they can have unpredictable consequences and require work unforeseen by the designers. Bhardwaj et al. (2019) study showed, for instance, that while on-board information and communication technology (ICT) hold the potential to increase efficiency, enable better communication between ship and shore, and reduce crew members administrative burden, evidence indicates that demands for more and more information from ships can in fact increase after the installation of new shipboard technologies. Lützhöft and Nyce (2008) noticed that as technology on board gets more automated and computerized, humans have often to engage in more co-ordination of resources and in what they call 'integration work' in which the seafarers perform work that the technology was intended to help them perform. They define integration work, as "a process, initiated and driven by the seafarer […] to construct a workplace that 'works' for them, given the tasks and duties they have to carry out" (Lützhöft and Nyce 2008, 59). The authors remind us that the accomplishment of a functioning work system consisting of humans and technology is not a stable entity but "a constantly changing ensemble of actors and artefacts" and is dependent on crew members' ongoing work of tinkering, adapting, synthesizing and aligning different parts of the system (representations, resources and processes) into a functioning whole, either by tailoring with the technology or with the tasks performed (Lützhöft and Nyce 2008, 66).

Managerial surveillance, autonomy and the interpretation of technology

The way technologies are implemented, including managers' purposes or agendas behind the implementation as well as how these intentions are interpreted and perceived by the seafarers, also play a role in the outcomes of new technologies. A number of researchers have analyzed and problematized current managerial ideas underlying the implementation of new technologies, as being part of a broader movement of increased bureaucratization and managerial surveillance of work at sea (Bhardwaj, 2013; Bhardwaj et al., 2019; Bhattacharya, 2012; Knudsen, 2009; Sampson et al., 2019). A common rationale behind the ambition to automate and digitalize more of the work traditionally performed by humans can, according to Bhardwaj (2013), be understood as a Tayloristic[2] tendency in the maritime sector aiming at "codification and 'routinization' of knowledge" and a "fragmentation of work into discrete tasks through detailed instructions and supervision, and a division of labor consisting of a clear distinction between those who manage work and those who actually perform the work" (Bhardwaj, 2013). Similarly, Sampson et al. (2019) argue that the prevalent management philosophy in 21st century shipping can be characterized by reduced autonomy of seafarers and increased bureaucratization of onboard work in combination with a mistrust of seafarers, fueled by a punishment-centered culture and, one might add, frequent reports postulating human error as the main cause of accidents (Schröder-Hinrichs et al., 2013). Sampson et al. (2019) argue that since "international regulators have sought to increase control over ship operators resulting in high levels of bureaucratization" many shipping companies have, as a reaction to that, "sought to exert maximum control over their professional seafaring officers". In doing this, shipping companies have, according to the authors, incrementally replaced their reliance on the judgement of professional officers by the introduction of technologies, procedures and rules. This has also been accompanied by a reduction of the size of the crew and an increase in administrative work (Ljung and Lützhöft, 2014). Sampson et al. (2019, 651) state that "tasks which were previously carried out in accordance with the judgement of senior officers have become transformed into activities which follow a set of prescribed steps (designed by shore-side managers)". They argue further that the erosion of seafarers' autonomy has been facilitated and made possible by "technological innovations providing

[2] After the American mechanical engineer Frederick Winslow Taylor (1965-1915) who sought to improve industrial efficiency through his principles of scientific management.

greater opportunities for shore- based personnel to monitor/manage seafarers on behalf of their companies". They provide the example of satellite technology and computer software allowing managers to closely monitor the course, speed and engine performance of any particular vessel in real time.

A particular problem with this combination of technological control and reduced autonomy is, as discussed by Bhardwaj et al. (2019), that while managers are using new communication technologies primarily to control the activities of the shipboard staff, they are not prepared to assume more responsibility. This in turn may create a vicious circle with the lack of trust, increased bureaucratization and technological surveillance leading seafarers to withhold crucial information from managers in fear of being blamed, dismissed or prosecuted (Sampson et al., 2019).

In summary, the introduction, and mode of implementation, of new technologies can have consequences for the social relation between ship and shore. The ways in which work practices change and how crew members adapt or react to the changes are often difficult to predict. Instead of bridging the gap between ship and shore and supporting seafarers work and facilitating learning and the development of safer and more efficient practices, technologies, such as the automatic transmission of data related to ship location, fuel consumption and engine performance, can be used to facilitate twenty-four-hour monitoring and surveillance, mutual mistrust between seafarers and managers, a punishment-centered culture, and a discouragement of professional knowledge, judgement and seamanship. This is expected to lead to opposite consequences as both safety and energy efficiency depends on seafarers' work engagement and effort which is often invisible to managers (Nardi and Engeström, 1999; Orr, 1996; Suchman, 1995) and which easily reduces to the minimum required (mere rule compliance) when trust is low. Technologies and procedures that are implemented in order to centralize decision making (in the shore office) and take away the autonomy of seafarers (but leave responsibility), rather than support their work, are thus likely to be rejected by the crew and lead to degraded relationship between ship and shore (Grudin, 1988).

3 Theoretical framework: situating technologies in social, material and cultural practices

From a cognitivist to a practice-based approach in maritime studies

Motivated by the need for interdisciplinary research focusing on the implementation and adoption of new technologies and practices in maritime work, the analytical framework used in this thesis is grounded in the practice-based sociomaterial (PB) approach (Corradi et al., 2010; Gherardi, 2012; Miettinen et al., 2009). Rather than being a predictive theory, the practice-based (PB) approach is an umbrella term for a number of adjacent theories and perspectives with roots in the philosophy of Marx, Heidegger, Wittgenstein and the sociology of Bourdieu, Giddens and Garfinkle. Among the concepts and theories frequently associated with the PB approach are: situated learning (Lave and Wenger, 1991), communities of practice (Orr, 1996; Wenger, 1998), activity theory (Engeström, 1987; Nardi, 1996), actor-network theory (Latour, 2005), situated action (Suchman, 2007), workplace studies (Engeström and Middleton, 1996; Heath and Luff, 2000; Luff et al., 2000) and distributed cognition (Hutchins, 1995). While being different in several regards, the theories within the PB approach share many assumptions and assertions that distinguishes them from other paradigms, most notably cognitivism, rationalism and functionalism (Nicolini, 2012; Schatzki et al., 2001). The PB approach is, for instance, characterized by a common rejection of the taken-for-granted dualities between mind and body; social and material; cognition and action; structure and agency. Instead, it advocates a relational and performative ontology where things, activities and knowledge are seen as being mutually constituted (Gherardi, 2008). For instance, from the PB perspective, knowledge, technology and learning are seen as inherently related in ongoing socially, culturally and materially situated accomplishments, i.e. in sociomaterial practices (Corradi et al., 2010; Fenwick and Nerland, 2014; Gherardi, 2012). The addition of the adjective 'sociomaterial' serves the purpose of a reminder that practices are never merely social or material but that the social and material dimensions of practices are always mutually dependent, or constitutively entangled, with each other (Orlikowski, 2007). Neither technologies, knowledge nor human activity can be fully separated or understood in isolation from the other or from the context in which it takes place (Cecez-Kecmanovic et al., 2014; Sandberg and Dall'Alba, 2010). Professional knowledge of how to perform a work task skillfully or how to use a new technology, is conceived as inextricably tied to practitioners' collaborative practices and doings (Nicolini, 2011; Orlikowski, 2002). It is, in the words of Gherardi (2008, 517), a capacity of "participating with the requisite competence in the complex web of relationships among people, material artifacts, and activities". Knowing is thus understood as a situated collective activity, embodied and mediated by culture and technology (Nicolini et al., 2003).

The PB approach offers an alternative research paradigm to the traditional understanding of working, learning and knowing in maritime human factors/socio-technical systems (MHF/STS), which, as seen below, does not sufficiently address the adoption of new technologies as situated phenomena taking place in particular social, cultural and material contexts.

A majority of the mainstream studies in MHF/STS examine work and human-technology interaction in broadly cognitivist (computational and information processing) terms focusing on such constructs as situation awareness (Chauvin et al., 2008; Cordon et al., 2017; Sætrevik and Hystad, 2017; Sharma et al., 2019), mental workload (Hockey et al., 2003; Wu et al., 2017; Wulvik et al., 2019) and decision making (Chauvin and Lardjane, 2008). Many studies aim at modeling the user and/or validate and verify particular technologies under development (Costa et al., 2018) against some measure of human cognitive processing, such as decision making (Dhami and Grabowski, 2010), cognitive workload (Cummings et al., 2010; Gould et al., 2009; Grootjen et al., 2006), situation awareness (Man et al., 2018c; Øvergård et al., 2015; Pazouki et al., 2018), cognitive human/team performance (Cohen et al., 2015; Grabowski and Wallace, 1993) or usability (Costa et al., 2018; Man et al., 2018b).

The cognitivist perspective can be illustrated by Grabowski and Wallace (1993) separation of motor, perceptual and cognitive skills in their characterization of piloting in coastal areas. The lengthy quote below serves the purpose of illustrating the cognitive perspective in previous maritime research:

> In a simple transit scenario, the pilot takes data from the environment (ranges, bearings, distances from objects, lines of position) as he arrives on the bridge and begins the transit. This data is stored in his perceptual processor and memory. Lines of position, deviations from the channel centerline, and track keeping information are held in the sensory system's buffer memory while the data are symbolically coded. The pilot's cognitive system takes knowledge from long-term memory-past experience with deviations from the present track, procedures from the Rules of the Road governing the conduct of vessels, courses to steer and closest points of approach, and "good seamanship" recommendations-and sensory images stored in working memory. The resulting information is used to make decisions about how to conduct the vessel through the waterway (Grabowski and Wallace, 1993, 1510).

The underlying premise of the traditional positivist and nomothetic approach in the MHF/STS research field is that "if the human factor is taken into account, a tight fit between person and design can be achieved and the technology is more likely to fulfill its intended purpose" (Horberry et al., 2008, 12). Investigations of the human factor are therefore often performed with the intention to identify the inherent limitations and capacities of human performance and the notion of fit between system elements is primarily conceived in cognitivist, rationalist and functionalist terms. Being a science mostly interested in prediction it often assumes that technologies determine human behavior and performance. From such a perspective, work, knowledge, interaction and professional skill onboard ships is often separated from its social, cultural and material context and reduced to a sequence of mental or technological information processes (Gould et al., 2009; Itoh et al., 2001; Lee and Sanquist, 2000).

Cognitivism can also be found in many more recent approaches in maritime studies, in particular those that stress the importance of having a socio-technical perspective. The STS approach in maritime studies has utilized several different theoretical modeling frameworks including Functional Resonance Analysis Method (FRAM) (de Vries, 2017; Patriarca and Bergström, 2017; Praetorius et al., 2015), Joint Cognitive Systems (JCS) and resilience engineering (Praetorius and Hollnagel, 2014; van Westrenen and Praetorius, 2012a, 2012b), distributed cognition (Nilsson et al., 2012), Work Domain Analysis (WDA) (Bisantz et al., 2003; Boström, 2018; van Westrenen, 2010), distributed situation awareness (Øvergård et al., 2015; Sandhaland et al., 2015), general control theory (Bjørkli et al., 2006; Costa et al., 2017; Olsson and Jansson, 2007; Øvergård et al., 2009; Petersen, 2004). While being formulated for slightly different purposes, these frameworks build on strikingly similar ontologies and epistemologies, i.e. share several theoretical assumptions and methodological practices, as the classical cognitivist models.

Suchmans' (2007, first edition in 1987) work is often cited as one of the first attempts to reconceptualize the traditional view on human-machine interaction, together with the work of Lave (1988) and Hutchins (1995). They contributed with changing the focus in several disciplines studying technology and work, from an exclusive interest in information processing, cognitive modeling, representation and function allocation to placing practice, context and culture at the center of attention. They popularized the perspective that the use of technology and its role in collaborative work is always contingent on the social, cultural and material context. Hence, in order to understand the human-technology relationship, whether on a macro (society), meso (organization) or micro (interaction) level, researchers in a variety of fields started to investigate technologies *as* practices.

Workplace studies (Engeström and Middleton, 1996; Heath and Luff, 2000; Luff et al., 2000; Szymanski and Whalen, 2011), for instance, emerged as a reaction to the inability of the traditional approaches to HCI and the sociology of technology and work to account for and explain why new technologies and technical systems often fail when deployed within organizations, i.e. why they are underexploited or rejected by its users. Researchers from the field of workplace studies argue that this limitation of previous approaches stem from "the widespread, though misfounded, assumption amongst both management and engineers, that work practices will naturally and unproblematically adapt to the new technology, enabling personnel to take advantage of the 'obvious' benefits afforded by new computer based systems" (Heath et al., 2000, 301).

Suchman (2007) argued that the interactional difficulties encountered by the users of the copying machines she studied was less a function of inadequate technical skills or interface design than of the users' lack of familiarity with the particular machine. Her point was that reading a new artefact is always an inherently situated and problematic activity and that "however improved the machine interface or instruction set might be, this would never obviate the need for learning on the part of the prospective user" (Suchman et al., 1999, 394). Later, Suchman argued in her studies of centers of collaboration (air traffic control) that technologies are "constituted through and inseparable from the specifically situated practices of their use".

> Rather than a network of computer-based workstations in which information is stored, we observed an array of partial, heterogenous devices brought together into a coherent assemblage on particular occasions of work. To be made useful, these devises needed to be read in relation to each other and to an unfolding situation (Suchman et al., 1999, 399).

Consequently, workplace studies emerged as a response to researchers' neglect of the "ways in which new technologies feature in practical organizational conduct" (Heath and Luff, 2000, 4). In contrast to the traditional cognitivist view, dominating early phases of disciplines such as HCI, cognitive science and AI, workplace studies reject the idea that human conduct or performance can be appropriately explained in terms of individuals' or systems' general ability to process information (including mentalistic constructs such as workload or situation awareness). Heath et al. (2000, 310) argue that "the individualistic and cognitive conception of the user found within certain forms of HCI, and which pervades our current understanding of system use, provides a curiously impoverished image of the ways in which tools and technologies are used; removing the practical intelligence critical to the competent deployment of artefacts in practical circumstances". Instead, workplace studies aim at exploring and understanding "the ways in which artefacts are 'made at home' in the workplace, and demonstrate how the use of even the most seemingly 'personal' computer rests upon a complex social organization; an indigenous and tacit body of practice and procedures through which tools and technologies gain their occasioned sense and relevance within workplace activities."

The cognitivist perspective can be contrasted with the PB approach which does not suggest any particular hypotheses but offers analytical framings and orientations, to be used in conjunction with an ethnographic methodology, in order to explore, explain and understand the socially, culturally and materially situated dynamics of work (Feldman and Orlikowski, 2011). Instead of entering a field with too many pre-conceptions about how things are done and the problems and challenges to be resolved, the PB perspective recommends an empirically driven approach to theory building. Systems or organizational structures should not be circumscribed by preconceived boundaries or predefined processes, but empirically studied as accomplished *in situ*. The researcher is encouraged to acknowledge possible discrepancies between how work is imagined to be done (formal) and how it is really done (Brown and Duguid, 1991; Feldman and Pentland, 2003). Schultze and Boland (2000, 194) argue that it is essential to adopt a PB approach when designing and implementing technologies in order to capture 'what people "actually" do rather than on what they say they do or on what they ought to be doing'. What counts as an improvement, or a good technology useful for work, sometimes differs between users, designers and managers. The skills required for work are not always visible to managers as for instance described by Bhattacharya (2012) who found a fundamental difference between seafarers' and managers' understanding of the value of the safety management system onboard. Seafarers believed that the system merely offered generic information about work procedures, which did not help them in coping with all contingencies that arose during the course of their job. Managers, on the other hand, were convinced that the system was doing its job as long as crew members complied to it.

It is important to acknowledge that the distinction between work as imagined and work as done is not, as sometimes suggested by the human factors literature, simply that between rule compliance and deviation, but rather that between practices as performances and their ostensive (formulated) representations (Feldman and Pentland, 2003). Even practitioners and researchers cultivate representations of their own and others' work. Moreover, "work as done" cannot be fully captured by organizational flowcharts or structural system-models since practices involve tacit knowledge, informal communication, interaction and improvisation. Studying work as done means that one has to acknowledge that work cannot be understood as the application of a transferable blueprint or plan, but as knowledgeable situated action (Suchman, 2007). Hence, in order to analyze work as done "from the inside" it has to be based on thick descriptions accounting for contingencies and context to yield understanding of how work is accomplished and how technologies are adopted.

In summary, the MHF/STS approach dominating maritime studies on technology and work can be contrasted to the approach used in this thesis shifting the unit of analysis from cognitive processes and systemic information processing to culturally situated sociomaterial practices. This thesis is, however, not the first to introduce a practice-based perspective on maritime issues. The approach focusing on culture, practices and socially situated actions has been used in maritime studies, most notably by Christer Eldh (2004) in his ethnography on safety on a passenger ship and in Sellberg's studies on instruction and learning in full mission ship simulators (Sellberg, 2016, 2017a; Sellberg and Lundin, 2017, 2018). However, it is still a relatively unrecognized approach in maritime studies and it has not been used in any study of energy efficiency and the adoption of technology before. Pan and Hildre (2018, 380) argued, for instance, that "the in-situ work practices of marine operators and marine engineers are largely invisible because they are typically unobserved" and that "failure to recognize the nature of work practices can lead to oversimplified, incomplete, and outdated knowledge about work circumstances and thus result in poor performance of certain engineered systems". Pan and Hildre (2018) suggest that research in maritime domain requires field studies making in-situ work practices within cooperative work environments visible.

The practice-based perspective on the adoption, enactment and appropriation of technologies

This thesis draws on various concepts from the repertoire of the PB approach to investigate the adoption of technologies supporting energy efficiency in shipping. The PB approach to technology rejects the assumption that technologies have a direct causal impact on organizational productivity, safety and efficiency, and is critical of the research methodology where either technologies, humans or organizations are reduced to 'variables' assumed to stand in some discernable and predictable relationship (Barley, 1986; Boudreau and Robey, 2005; Feldman and Orlikowski, 2011; Gherardi, 2010; Leonardi, 2009; Leonardi and Barley, 2010; Orlikowski, 1992, 2000; Orlikowski and Scott, 2008; Rivera and Cox, 2013; Vaast and Walsham, 2005). According to the PB approach the traditional conception of the impact of technology on organizational performance "fails to account for the diverse ways in which a technology is appropriated and utilized by workers, and the non-uniform manner in which it structures individual and organizational action

(Orlikowski, 1992, 402). Researchers in the PB tradition argue that technologies, in themselves, lack any inherent or predetermined structuring or organizing abilities or effects. From this perspective, technologies remain inanimate and ineffectual unless they are apprehended, activated and given meaning through their deployment and appropriation in organizations. Orlikowski points out that "until such time as these [technologies] are actually used in some ongoing human action - and thus become part of a process of structuring - they are, at best, potential structuring elements, and at worst, unexplored, forgotten, or rejected bits of program code and data cluttering up hard drives everywhere."(Orlikowski, 2000, 406).

As opposed to the treatment of technologies as discrete entities with predetermined causal effects, a practice-based perspective posits a view where the adoption, appropriation and effects of technologies "emerges out of an ongoing stream of social action in which people respond to the technology's constraints and affordances, as well as to each other" (Leonardi and Barley, 2010, 5). The appropriation, modification, rejection or use of technology, by a community of practitioners, enacts a particular *technology-in-practice,* that is, a "repeatedly experienced, personally ordered and edited version of the technological artifact, being experienced differently by different individuals and differently by the same individuals depending on the time or circumstance" (Orlikowski, 2000, 408). The adoption and use of a particular technology can, according to Orlikowski, be influenced by several individual, social, cultural, material and institutional factors:

> When people use a technology, they draw on the properties comprising the technological artifact - those provided by its constituent materiality, those inscribed by the designers, and those added on by users through previous interactions [...] People also draw on their skills, power, knowledge, assumptions, and expectations about the technology and its use, influenced typically by training, communication, and previous experiences [...] These [experiences] include the meanings and attachments - emotional and intellectual - that users associate with particular technologies and their uses, shaped by their experiences with various technologies and their participation in a range of social and political communities. Users also draw on their knowledge of and experiences with the institutional contexts in which they live and work, and the social and cultural conventions associated with participating in such contexts. In this way, people' s use of technology becomes structured by these experiences, knowledge, meanings, habits, power relations, norms, and the technological artifacts at hand (Orlikowski, 2000, 410).

In an extension of Orlikowski's theory of technologies-in-practice, Leonardi (2011); Leonardi (2013) proposes a theory of how technologies become intertwined with social agency and practice, forming specific technologies-in-practice, as well as how they might change over time. Leonardi (2011) term for the process of intertwining is imbrication. The process of imbrication is explained in terms of technologies' materiality and humans' perception of a particular technology's affordances and constraints. Users make choices of how they will imbricate the material agency (function) of the technology with their own human agency (will), that is, how they will appropriate the technology, change its material agency (by reconfiguring the technology) or change their practices surrounding the technology to meet their goals. Technologies can be perceived to have different affordances and constraints depending on the perceiver, and users can choose to imbricate human and material agency in different ways. Technologies are thus both physically constructed by actors working in a given social context, but they are also "socially constructed by actors through the different meanings they attach to it and the various features they emphasize and use (Orlikowski, 1992, 406). The way towards an imbrication (forming of a routine or technology-in-practice) can moreover be a long process, requiring work, effort and often involve accumulations of past changes and previous imbrications.

The interpretive flexibility of technology

Researchers in the PB tradition argue, as seen in the previous section, that technologies are *interpretively flexible,* acknowledging that technologies can often be interpreted and appropriated in many different ways depending on the relationship a user forms with a technology (Barley, 1986; Leonardi, 2009; Orlikowski, 1992, 409). This does not mean, however, that the interpretive flexibility of any given technology is infinite. The interpretation, adoption and use of a technology is always constrained both by the material characteristics of the technology and by the institutional contexts (structures of signification, legitimation and domination) as well as by the different levels of knowledge and power affecting actors during the technology's deployment (Orlikowski, 1992). Two implications follow from the interpretive flexibility of technologies. The first is that "the actual functionality" of the technology—the criteria by which individuals determine what the technology is supposed to do and by which they evaluate whether or not it does that—varies significantly among the diverse groups associated with it "(Leonardi, 2009). This means that the interpretation and enactment of a technology is only provisional and can differ between sites, communities and socio-cultural contexts and over time. The second implication is that technologies are "never fully stabilized or 'complete', even though we may choose to treat them as fixed, black boxes for a period of time" (Orlikowski, 2000, 411). Instead technologies are "always temporally emergent through interaction with humans in practice" (Feldman and Orlikowski, 2011, 1246). When viewing the adoption and use of technology through a practice lens, "the specific outcomes of stability or change are seen as consequential only in the context of the dynamic relations and performances through which such (provisional) stability and change are achieved in particular instances of practice (Feldman and Orlikowski, 2011, 1249). However, it is also the case that once adopted and deployed in organizations or work settings, technologies tend to become "reified and institutionalized, losing its connection with the human agents that constructed it or gave it meaning, and it appears to be part of the objective, structural properties of the organization" (Orlikowski, 1992, 406).

Communities of practice and activity systems

The enactment of technology, or the imbrication of social and material, is, according to the PB view, not an isolated independent choice of an individual user but the result of a collective interaction.

> A community of users engaged in similar work practices typically enacts similar technologies-in-practice, where through common training sessions, shared socialization, comparable on-the-job experiences, and mutual coordination and storytelling, users come to engage with a technology in similar ways (Orlikowski, 2000, 411).

In order to understand the collective adoption of technologies, the notion of communities of practice is useful. Communities of practice are, according to Wenger, first and foremost the social constellation in which "we experience the world and our engagement with it as meaningful" (Wenger 1998, p. 51). It is within communities of practice that practitioners negotiate the meaning of their work and the technologies used. Communities of practice are held together by mutual engagement, a sense of a joint enterprise and a shared repertoire of tools. Although every work practice is situated in a broader organizational and institutional context, with its particular requirements, constraints and resources, communities of practice are not determined by these conditions but respond to them and thus define the enterprise. The impact of an external force, such as the decision of a manager or the implementation of a new technology, is thus always mediated by the community's own re-production of practice (Orr, 1996). Rather than only being controlled from the outside, communities of practice have their own mechanisms for internal discipline. The negotiation of a joint enterprise gives rise to norms of mutual accountability among the participants including a sense of "what matters and what does not, what is important and why it is important, what to do and not to do, what to pay attention to and what to ignore [...] when action and artefacts are good enough and when they need improvement or refinement" (Wenger 1998, p. 81). Through this process a *shared repertoire*, consisting of the activities, routines, ways of doing things, symbols, technologies and artefacts is developed. Technologies-in-practice, are thus meaningful enactments that emerge through participation in communities of practice and, at the same time, the concrete "points of focus around which the negotiation of meaning becomes organized" (Wenger 1998, p. 58). To become a meaningful part of a practice, technologies have to be appropriated in the communities of practice.

According to Dourish (2003), technological appropriation involves two things. The first is "that features of the system itself become meaningful" i.e. that "people develop ways of understanding how the representations that the system might offer are consequential for their work, and how these representations incorporate and refer to other meaningful entities (people, documents, appointments, or whatever)". Secondly, that the "technology conveys meaning". That is, that the system becomes "a means by which people can see (and then interpret and understand) the actions of others" (Dourish, 2003, 485).

This definition of appropriation is relevant for the understanding of the adoption of technologies supporting energy efficiency in shipping. It implies that in order for technologies supporting energy efficient ship operation to be collectively adopted and used by seafarers they need to play a role within the system of meaning constituting the operation and management of ships. First, seafarers need to develop ways of understanding how the representations that the system might offer (various parameters related to energy consumption) are consequential for their work of operating the ship and how these representations relate to the totality of rules, regulations, practices and policies. Second, the representations need to become a meaningful part of the communication and collaboration with other colleagues and shore managers.

However, previously enacted technological and organizational structures might inhibit the adoption of new technologies and practices. Since the process of adopting, appropriating and using technology is, from the PB perspective, understood as a dynamic and dialectical process embedded historically and contextually, it can also be contradictory and involve tensions between elements of the practice that stand in opposition to each other. In particular, the adoption of technologies can be limited if it creates contradictions or tensions in the activity systems forming the work of practitioners. From an activity theory point of view, sociomaterial practices are always directed at achieving certain objectives (Engeström, 2000; Nardi, 1996). They consist of subjects, rules, tools, communities and a division of labor. However, sometimes the objectives cannot be achieved because of tensions between the components of the activity system. The use of a new technology might, for instance, stand in contradiction to the norms or responsibilities of practitioners, hence making its adoption a problematic task (Engeström, 2001). The adoption of technology therefore often depends on the resolution of contradictions introduced with the technology.

In summary, from the PB perspective, the adoption, appropriation and use of new technologies is seen as an inherently social, cultural and material phenomena. The adoption of a technology by a particular group of practitioners is essentially a matter of incorporating the use of the tool into the embodied know-how and everyday practice of the practitioners (collective and situated activities). For a technology to become adopted, appropriated and used it is required to make the artefact a recurrently enacted technology-in-practice, an imbrication between human and non-human elements. Successful integration can be understood as a constitutive entanglement between social and material elements, a sociomaterial imbrication. A technology-in-practice is a way of interpreting, understanding and using the technology that is relatively stable in time and socially recognized. The adoption of technology is thus not the same as the installation of technology but requires work, learning, negotiation and social interaction to render the technology a meaningful tool in practice. Over time, the enacted technology-in-practice may become embodied, routine, taken for granted, and even institutionalized within certain circumstances. However, not all introductions of new technologies lead to smooth integration with practice but can be resisted by certain communities if seen to create disruptions to the established social and cultural orders by challenging the established practices and the socially defined competences or if contradictions are created in practitioners' activity system.

4 Methodology: Ethnography and Naturalistic field studies of work

In order to be able to study the sociomaterial nature of energy saving onboard ship a qualitative methodology is appropriate. The purpose and value of a qualitative, or interpretative, research method is that it allows examining the social context and subjective perspectives and practices of humans. It can be argued that without an understanding of peoples' contexts of action and perspective it is impossible to understand the reasons for their actions.

A methodological implication of the theoretical orientation adopted in this thesis is that technologies, work and social context cannot be understood, and should therefore not (only) be studied, independently from each other, as is usually the case in experimental or laboratory (simulator) research. Research on how technologies affect and influence work practices, skills and performance can only meaningfully be conducted "in the wild" in order to increase ecological validity and make sure that the research is made relevant for the actual 'applied' setting (Rogers and Marshall, 2017). While most traditional human factors methods have employed laboratory (simulator) trials to evaluate technology there is also a large body of research in HCI and CSCW that since the late 80s has utilized field work, and in particular ethnography, as a means for both design, evaluation and the analysis of technologically mediated work (Blomberg and Karasti, 2013; Button and Sharrock, 2009; Plowman et al., 1995; Randall et al., 2007; Szymanski and Whalen, 2011). Many of these studies have conducted careful investigations of work flows and practices and what happens after the installation of a technology into a setting (Nardi, 1997).

According to Blomberg and Karasti (2012), a handful of principles define ethnography in studies on work and technology. These include studying phenomena in their everyday settings, taking a holistic view, providing a descriptive understanding, and taking members' perspective. The ethnographic focus on *everyday settings* follows from the view that to understand the impact of technologies you must gather information in the actual workplace where it is supposed to be used. *Holism* emphasizes the importance of understanding activities as taking place in a particular context with an array of related activities by investigating the particular logic of people's practices from the *perspective of members*. Moreover, ethnographers have a commitment to *describe events and activities* as they happen, rather than passing on judgments of the efficacy of people's everyday practices. This means that ethnography favors what (Ryle, 1949) calls 'thick descriptions', i.e. descriptions of work and the use (or non-use) of technologies that are rich and detailed enough "to make some observed behavior understandable" (Harper, 2000, 244). Consequently, it also favors process-oriented research designs over outcome studies, and ideographic, interpretive accounts over nomothetic approaches (DeSanctis and Poole, 1994). The main virtue of ethnography in studies of technology use lies, according to for instance Crabtree et al. (2000), in its ability to make visible the real-world sociality of a setting. The overarching goal of naturalistic studies in the wild "is to understanding how technology is and can be used in the everyday/real world, in order to gain new insights about: how to engage people/communities in various activities, how people's lives are impacted by a specific technology, and what people do when encountering a new technology in a given setting" (Rogers and Marshall, 2017, 1).

In his discussion of research programs for organizational ethnography aimed at investigating work and the role of technology Harper (2000, 244) described ethnography as "a method for understanding what activities mean to the people who do them". Three advises for how to conduct an ethnography are given in that paper. The first is to map out the key processes within an organization or a workplace and to recognize the salient junctures in the processes by following the "life cycle" of information, that is how information is "marshalled, is worked up, reviewed, circulated, used, stored, and then forgotten about" (Harper, 2000, 246). For this thesis this meant observing the work of the crew members before, during and after voyages, mapping their interactions and following the information related to energy efficiency and consumption as it traveled (or got stuck) between technologies, departments or individual deck and engine officers. The second advise has to do with building rapport and being treated, by the practitioners under study, as someone who is really interested in and can acquire the ability to describe the practitioners' work from "the inside". This is often described as a difficult task for an outsider researcher with no domain background (as in my case) but can, according to Harper, be achieved by taking part in certain "ritual inductions". For my part, spending many hours onboard the ships, sometimes staying up and talking to seafarers throughout the night, listening and responding to personal stories and experiences of work at sea, contributed to the sense that the seafarers were, in fact, describing their work from the inside rather than giving me "the official version". It is not always easy to get those interviewed to believe that the researcher is really interested in their perspective rather than to investigate whether they comply to the rules. I had, for instance, often to assure the crew members that I did not work for the company but was an independent researcher (PhD student). The last advise of the program proposed by Harper (2000, 256) relates to the aim behind the interviews and observation of work which is to "get to the organization of the work at a level that reflects the practical concerns of the individuals who undertake it".

Several commentators on the use of ethnography in workplace studies have pointed out that ethnography is not just a set of methods, such as interviews or observations (although these certainly are required) but requires some "analytic sensibility", or "explanatory framework" that conditions the observations or the descriptions and accounts for what is observed (Anderson, 1994; Button, 2000). In the social sciences, ethnography is, as emphasized by Anderson (1994), a form of analytic reportage rather than a form for data collection. While most ethnographically grounded workplace studies have used ethnomethodology as an analytic framework, other practice-based approaches, such as that used in this thesis are possible, as argued by for instance Sharrock and Hughes (2001).

Research setting and case studies

The ethnographic fieldwork conducted for this thesis took place onboard 11 ships in two Swedish shipping companies. The research setting of the first case study was onboard five passenger ferries operated by a company with 37 vessels in operation on 20 ferry routes between ten countries in Northern Europe. The work onboard the selected ships in the company was deemed to be an interesting setting for a study about the social and organizational aspects of energy efficiency in shipping because of the company's concern about sustainability and energy efficiency. In 2006 the owner of the shipping company had decided to introduce an energy target aimed at an annual 2.5% energy reduction and initiated an installation of an energy monitoring system onboard all the ships in the fleet. The energy monitoring system afforded both real-time monitoring of fuel consumption, through sub metering of various consumers (machine systems), and long-term storage and visualization of data on various variables relevant for energy consumption, such as wind, currents and ship draft. A number of deck officers and engineers from each ship had been sent to a one-day course about the system and then given the direction to use the technology in whatever way they found suitable. The five ships were selected, based on a convenience sampling, together with representatives from the company who were positive to a study investigating the human dimension of energy efficiency.

This second study was conducted in another Swedish shipping company owned by a larger international corporation within the transportation industry focusing on public transport. The shipping company owns 16 vessels and charters two, with an individual ship capacity of around 200–400 passengers. The shipping company uses the ships to provide their service for a local transportation company owned by the regional municipality responsible for delivering public transportation to the citizens. The service delivered is primarily to transport passengers between several islands within an archipelago and along a river separating a city. The company was purposely chosen for the case study because it was known for having reduced its fuel consumption by 20% as a result of installing a fuel-monitoring system onboard its ships and had thus demonstrated that significant improvements in operational energy efficiency could be made without large investments and resulting in high return on investment. The organizational process that the company and in particular the officers working on the ships had experienced was therefore, considered to be a valuable case to study to better understand how energy-monitoring information systems are adopted by crew members and how they may enhance the everyday operational practices in shipping.

Data collection

Case study I

The data collection performed in the first case included extensive field studies onboard five ferries. The methods used involved observations, interviews, document analysis, and examination of the use of artefacts. The combination of observation and interviews is particularly useful when studying work practices because it reflects both practitioners' beliefs and actions (Silverman, 2014). The aim of the data collection method chosen was to capture and document the practices, beliefs, understandings, feelings and actions of the crew members in two ship departments. The deck department included masters (captains) and navigating officers and the engineering department included chief technical engineers and technical engineers.

The fieldwork was conducted during one year of recurrent visits onboard the ships (April 2015- June 2016) in order to allow intermittent and iterative analysis. Each field visit consisted in one round trip at a time (back and forth between destinations). Each roundtrip lasted between 10 – 39 hours. In total, 28 sea voyages (4 and 14 h) were made and approximately 24 working days (195 h of observation) were spent on the ships at sea or when berthed.

The observations were primarily made on the bridge and in the engine control room (fig. 1 and 2) but also in many other places onboard such as car decks, offices, messes, and many other compartments where crew members worked and lived. The observations focused on the cycle of work starting before voyages (e.g. cargo planning and loading, engine preparation, unmooring), during the execution of voyages (e.g. harbor maneuvering, open sea navigation) and after voyages (discharging of cargo, administrative and maintenance tasks). The observations covered many different practices regarding energy efficiency, such as navigation, maneuvering, trim optimization, ballast water use, engine load, cargo handling, autopilot use, and performance monitoring.

Semi-structured interviews (conducted in Swedish) were held with 40 crew members (Master Mariners, Officers, Chief Engineers, Engineers). The interviewees ranged from novices (3rd officers with only a few months of experience and seniors and Masters, with several years of experience). The interviews lasted between 30 and 120 minutes and covered questions related to the crew members' work with energy efficiency, the technology they used and the challenges they perceived in improving energy efficiency. Verbal data also consisted in conversations between crew members during work and spontaneous dialog between crew members and the researcher during the observations.

Figure 1. Engine control room


Figure 2. Ship bridge

In addition to the field studies onboard the ships a focus group was held with four project leaders in a group onshore responsible for the implementation of technologies for improving energy efficiency. The main purpose of the focus group was to understand the work of the group and their perspective on the installation of the energy monitoring system investigated in paper II and energy saving practices onboard the ships. The focus group lasted for 2 h and took the form of a semi-structured discussion. The data were also complemented with an interview with the designer of the system in paper IV in order to get an understanding of the intensions and methods behind the system as well the designer's view on the implementation process of the system on the two ships in the analysis. All interviews were audio-recorded and fully transcribed and the observations were captured by notes and memos during and after each field visit.

Case study II

The data collection performed in the second case study was based on semi-structured interviews with 12 bridge officers working on 6 different ships, supplemented by observation of work carried out by the officers (maneuvering, navigation, maintenance). The ships did not have any engine department onboard so no engineers were interviewed. The interviews (conducted in Swedish) and observations took place between February and April 2018. The interviewees were encouraged to retrospectively elaborate on the events that took place during the implementation process of the monitoring system investigated in paper III. This was done to be able to capture and interpret the temporally meaningful narrated episodes of the introduction of the system and the broader issue of energy saving related to their work (Flick, 2000). The interviews onboard the ships often lasted several hours (on average 3 h) as they were entangled with the observations during the voyages. The observations focused on how the system was used in practice and on the methods of saving energy during ordinary work that had been developed as a result of using the system (fig. 3). In addition to the observations and the interviews with the officers onboard the ships, one semi-structured interview was also held with a representative of the shore organization: the environmental manager. The manager had been responsible for introducing the system onboard and had appeared in public (conferences and media) speaking about the company and its environmental work. The researcher also attended a full day workshop that the company held with their employees covering topics related to sustainability and eco-shipping. Table 1 gives an overview of the data collection carried out as part of this thesis and figure 4 gives an overview of the different papers generated in the two case studies.

All participants in both case studies gave their consent for participating in the study and were informed that they could withdraw their contribution at any time. The recorded and transcribed data was anonymized and stored in a way that only gave the research access to it.

Figure 3. Ship bridge

Table 1 Data collection (overview)

	Case study I	Case study II
Time period of data collection	April 2015 - June 2016	February - April 2018
Observations (h)	195	36
Interviews (persons) (deck department)	21	12
Interviews (persons) (engine department	19	0
Interviews (persons) (shore office)	4	1
Setting	5 large ferries	6 small ferries

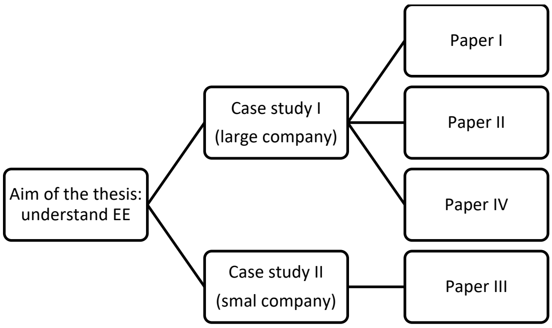

Fig. 4 Case studies and papers

Data analysis

> Qualitative data analysis is the classification and interpretation of linguistic (or visual) material to make statements about implicit and explicit dimensions and structures of meaning-making in the material and what is represented in it (Flick, 2014).

Field notes from the observations and recordings from the interviews in each separate case study were transcribed verbatim by myself, generating over 300 pages of transcripts. The analysis of the material (collected data) followed a thematic analysis approach with the help of sensitizing concepts provided by the interpretational theoretical framework found in the practice-based approach. Thematic analysis is an approach to the analysis of qualitative data that allows rich descriptions of the data set as well as detailed accounts of one particular aspect, is compatible with both inductive and theoretically driven analyses grounded in both essentialist/realist and constructionist approaches (Braun and Clarke, 2006).

Data analysis is a recursive process involving a constant moving back and forth between the entire data set, the coded extracts of data, and the emerging analysis of the data in order to generate and describe themes in the material. A theme, according to Braun and Clarke (2006, 82), captures something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set". Analysis is not a linear process or a mechanical categorization or coding but requires interpretation. It can, nevertheless, be described as consisting of a number of elements (Braun and Clarke, 2006):

(a) familiarization with data: immersing oneself in the data by re-reading the transcription of the verbal (interview) and observational material;
(b) initial coding: identifying and organizing features of the data that appear interesting;
(c) searching for themes: sorting the different codes into potential themes;
(d) reviewing themes for internal homogeneity and external heterogeneity;
(e) interpreting and conceptualizing the themes in relation to the data;
(f) providing a concise, coherent, logical, non-repetitive and interesting narrative account of the story that the data tell.

The analysis process in this thesis included the identification of re-current patterns in the data, categorized into themes and then compared and analyzed across voyages, departments, individuals and ships in order to explore the dimensions of the identified themes, focusing on recurrent patterns in the interactions between crew members and different technologies supporting onboard work for improved operational energy efficiency. The overarching theme explored in this thesis (the adoption, appropriation and enactment of technologies), described in the different papers, emerged through a systematic combination of data analysis and theoretical framework building. Although the analysis was theoretically informed (by the practice-based approach to information systems), rather than purely inductive, the analytical process was recursive in the sense that the practice-theoretical framework used for analysis was continually developed and re-fitted to the themes emerging in the progressively coded data until a stable conceptual mapping was achieved between the theoretical and empirical parts of the study (Dubois and Gadde, 2002). In the final step of writing up the analysis, the themes were re-embedded into an analytical narrative illustrating the different themes and issues identified for the purpose of giving a rich description and illustration of the themes, enabling contextual understanding.

5 Results - Summary of the empirical studies

Paper I

Viktorelius, M., 2018. The Human and Social Dimension of Energy Efficient Ship Operation, in: Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F. (Eds.), Trends and Challenges in Maritime Energy Management. Springer International Publishing, Cham, pp. 341-350.

The first paper offers an analysis of some of the individual and collaborative practices related to energy efficiency enacted onboard the ships in the first case study. The aim of the study was to investigate the work practices and understand the nature of the skills and knowledge utilized in actual efforts on board ships to save fuel, as well as how these capabilities were developed in practice. The research questions addressed in this paper were: (1) What are the characteristics of knowledge related to the practical accomplishment of energy efficient ship operation? and (2) How can such knowledge be developed on board ships? Drawing on theoretical understandings informed by the practice-based lens on organization and work, this study focused on the local, embodied and social manifestations of energy efficiency knowledge and knowing onboard the ships (Nicolini et al., 2003).

The debate and research on energy efficiency in shipping frequently refers to the implementation of various "optimal" practices in ship operation, including voyage optimization, speed optimization etc. These so called "measures" are conceptualized as discrete and isolated from each other and assessed according to their estimated potential (Bouman et al., 2017). The notion of "optimal practice" is, as seen in chapter 2, often understood in terms of calculations of what is technically possible and cost-effective. However, since the logic of professional practice and knowledge often differs from scientific abstractions it was important to understand how the knowing related to energy efficiency was manifested in the work onboard the ships in order to do justice to the practical logic underlying the practice of seafarers. (Sandberg and Tsoukas, 2011).

As expected, crew members expressed an understanding of optimal that differed from the purely techno-economic notion circulating in the policy and research discourse. For them, energy efficiency could not be reduced to a simple formula or ratio of the desired output (cargo mass multiplied with distance traveled) to required input (used resources). The basis of their understanding of service demand (transport work) and optimality was not a detached or abstract calculation but experienced based and situated in the professional practice and norms of their everyday activity. The meaning of expressions such as "the implementation of measures" or "optimal voyage execution" did not make sense from the perspective of the practice of crew members since they already did what they thought was optimal, even if it was not considered energy optimal at all times. Neither did it make much sense to think of operational energy efficiency in terms of distinct 'measures' to be implemented, in analogy to the installation of a pump or fan, having an immediate and automatic effect. Operational energy efficiency was seen as a much more complex phenomenon depending on a larger set of factors including both the seafarers' ordinary activities but also several factors outside the control of the crew members.

From the interviews with the masters, officers and engineers it soon became clear that energy efficiency was considered an aspect of almost everything, or every action, onboard the ships and it was thought to heavily depend on cooperation and communication during work. As such, it could not be separated from the central tasks of navigation, maneuvering, cargo loading, engine maintenance etc. This also meant that the activity of fuel saving was not an isolated practice, performed in addition to the other tasks onboard or something that it was sufficient to perform once in a while, but "a frame of mind" to be integrated with all other ship tasks. The knowledge needed for this kind of work was considered to be of a practical, action-oriented nature relying on engagement and experience but also on improvised situated action adapting to various contingencies during operation (cf. Gherardi, 2008).

The work with energy efficiency started already before the departures when loading the ferries with cars and trucks. Departures were considered the most stressful moment of the whole ship operation and required mutual understanding, experience and the ability to cooperate. Crews knew that time was of essence and that late departures meant higher speed at sea. The organization of the cargo loading process involved teamwork and communication between a large number of distributed crew members and port staff on the bridge, the different cargo decks, wharf and car check-in office. Senior officers responsible for leading the teamwork during cargo loading operations emphasized the importance of knowing each other well and having a good relationship and sense of team-spirit in order to make the cargo loading run smooth. The placement of the cargo (cars and trucks) was also thought to have implications for fuel consumption. A "bad distribution of weights" meant that extra ballast water had to be used which increased the displacement[3] of the ship and thus the resistance through the water. However, the time available for cargo loading and the amount or type of cars or trucks on each particular voyage did not always allow the officers to place the cargo the way they thought was optimal. Spending too much time on cargo placement could easily delay the departure and

[3] Displacement or displacement tonnage is the weight of water that a ship pushes aside when it is floating, which in turn is the weight of a ship (and its contents).

increase the require speed at sea. Hence, judgement had to be made on 'how perfect' the cargo placement could be on each occasion.

In the engine control room, the tasks related to energy efficiency were, in addition to regular maintenance, to prepare and start the appropriate number of engines and systems at the right time given the conditions (e.g. expected weather, required speed, approximate power demand) and unfolding of events (observed troubles during cargo loading, possible delays). Engineers had to be attentive to what happened during cargo loading since a premature startup of the engines meant waste of fuel. Moreover, the preparation and use of all available main and auxiliary engines were not always necessary under all circumstances (slower voyages, few passengers, good weather). The crew thus strived to reduce waste by adapting the number of engines used on a particular voyage to the specific circumstances. Since the optimal number of engines was not readily calculated by any system onboard it required a sense of what speed could be attained with how many engines in what weather conditions in order to arrive on time. This was, however, not always an uncontested or uncontroversial decision and crew members sometime disagreed on how many main engines to run in order to increase energy efficiency.

During harbor maneuvering masters were conscious of not using excessive engine power or all available thrusters when berthing or unberthing. However, on days with bad weather, this was sometimes necessary in order to control the ship and avoid accidents. How much power and what "style of maneuvering" to use were based on estimations before entering the harbor or leaving berth and situated micro decisions during maneuvering, corresponding to outer conditions and the masters' need to "feel safe". The knowing related to energy efficiency was thus tightly tethered to an embodied understanding of the ship and its behaviors in various circumstances. This was a particularly important knowledge also in the second case study (paper III) in which the vessels (working as seaborn busses) made frequent stops to pick up and drop off passengers and thus spent considerable time maneuvering.

Out on the open sea (case study I) navigators were concerned about keeping the most optimal speed given the scheduled arrival time as well as the present and expected weather and sea conditions. Knowledge related to energy efficiency in voyage execution, and in particular speed regulation, was often expressed as the ability of handling the ship in an balanced way by taking several situational factors into account, such as the varying strength and direction of the wind and sea currents, the varying water depth along the route, the distance and duration of the voyage, waves, traffic, the amount and type of cargo and time available to load the cargo in the next port, characteristics of the ship and engines, etc. The practical knowing used during the ship- and situation specific considerations during energy efficient ship handling also involved making frequent judgments regarding the tradeoffs inherent in the execution of the voyages, such as saving fuel vs. being on time. Optimal did therefore not only mean 'energy efficient' but also 'safe' and 'pleasant for passengers' (certain speeds and courses could generate vibrations, thuds or other unpleasant noises and movements during certain sea conditions). Unnecessary changes in course and speed to resolve traffic situations were seen as waste of fuel but were often made for safety and regulatory reasons. The knowing in relation to energy optimization was thus manifested as the ability to decide when to care for and when to ignore energy saving. Since the practice of the crew members contained many different objectives and focus areas, the most important of which was safety, it was crucial to know when acting on behalf of energy efficiency was unacceptable. Constant reading and early planning of the traffic situation was therefore seen as important in the act of balancing the concerns about safety and energy efficiency. Newer officers were generally considered less proficient in energy efficient navigation since this was thought to require an expert ability to handle dense traffic situations, be familiar with the ship and the route and be able to predict future situations in order to plan the navigation to avoid unnecessary changes in speed or maneuvers.

Knowing and learning related to energy efficiency was primarily based on personal and collective experience with limited organized attempts to manage the knowledge required for operational energy efficiency. The primary means of learning about energy consumption was through everyday observations of the ship in actual operations and trying out how the energy system as a whole reacted to different ways of operating. Although the work and knowledge related to energy efficiency had been left rather unmanaged, officers and masters tried nevertheless to save fuel through the methods and principles that had been developed through experience. Many local initiatives onboard individual ships had been made over the years which had contributed to different strategies for saving fuel but few efforts to share the knowledge between the ships or document the conclusions in order to share with later generations of crew members serving on the ships had been made. One consequence of this was that many different and sometimes contradictory convictions related to energy efficiency were held on the ships, and sometimes even within the same departments. The absence of a shared and less contentious knowledge base seemed to create uncertainty and a sense that it was almost impossible to fully comprehend, or settle on, how to realize an optimally energy efficient voyage. Nevertheless, sharing of knowledge related to energy efficiency between senior and novices took place through occasional discussions about energy saving. Situated instructions and guidance given by experienced officers to newer ones were considered important for learning the collective rules-of-thumb for fuel saving but were recognized by many officers and masters to lack in systematicity.

Conclusions based on paper I:

Crew members play a crucial role in operational energy efficiency. Knowledge related to the practical accomplishment of energy efficiency was shown to be locally, socially and materially grounded. While situated learning and personal experience was seen to play an important role in the accumulated competence related to energy efficiency, there was a clear need of more organized attempts to support and manage the knowledge onboard.

Paper II

Viktorelius, M., Lundh, M., 2019. Energy efficiency at sea: An activity theoretical perspective on operational energy efficiency in maritime transport. *Energy Research & Social Science* 52, 1-9.

This study investigated the implementation, adoption and use of a state-of-the-art energy performance monitoring and analysis system onboard five passenger ferries (case study I). The questions addressed in this paper were (a) how energy efficiency figured in the activity systems onboard the ships before the installation of the energy monitoring system and the introduction of the energy policy and (b) how the attempt to reconfigure the activity systems, by the energy monitoring tool and policy affected the work practice onboard.

At the time of the case study the shipping company already had an established organizational unit on shore working with energy efficiency and whose task it was to lead technical project for saving fuel. Although the unit (called the ESP group in the article) had been successful and many technical projects had been completed there remained a sense of frustration and disappointment, from the owner and managers' side, concerning the improvement of the operational practices onboard the ships. In particular, several managers on shore believed that not all crew members were motivated or had 'the right attitude' to save energy. Some also believed that outright laziness or technical incompetence were part of the explanation for why optimal operational energy efficiency was not yet achieved. For this reason, the company decided to install an energy performance monitoring system on all its vessels with the hope that the access to real-time fuel consumption data, and long-term storage and visualization of data on various variables relevant for energy consumption, would change onboard practices and 'behavior'.

Drawing on activity theory for data analysis (Engeström and Middleton, 1996), the findings in the study confirmed that the objective of operational energy efficiency was often compromised onboard the ships, but for reasons not fully appreciated by managers and which the sole installation of the energy performance monitoring system could not mitigate. Rather than being caused by low motivation, individuals' lack of knowledge or 'bad attitudes', the challenges of achieving optimal operational energy efficiency were found to be grounded in the materiality of the issue (the complexity of ship energy consumption), the present- and near future-directed nature of onboard work (attentional demand of ship handling), the superiority of other objectives such as safety, passenger comfort and service, as well as the current division of labor and resources. Being features of the activity system structuring work and action onboard, these contradictions could not be resolved merely by a technical measure, which was directed at crew members' informational sources, rather than the tensions on the activity system level. The challenge of improving energy efficiency in practice was not a lack of information but the organizational resources to analyze it onboard. The installation of the system and the energy saving policy had thus a limited effect on the operational energy efficiency of the ships.

It should be noted that the problem with the system was not primarily that it did not fit with human cognitive abilities. No obvious refinement of the interface design would have resolved the initial challenges of improving energy efficiency or addressed the contradictions that surfaced after the introduction of the monitoring system. The problem was thus not on the level of an isolated human interacting with a machine but rather on the level of the system of objectives, rules and division of labor mediating activity, i.e. the collective work practices. Indeed, the installation of the system and the access to real-time monitoring and historical data highlighted the inherent contradictions without resolving them. In particular, the system required new analytical and collaborative practices involving both seafarers and shore staff in order to facilitate ship operation. Except for an introductory course of the basic features of the system given to two seafarers on each ship, the company did not perform any implementation activities or collaborated with the crews for developing strategies of using the system. Interviews with shore personnel revealed that guidelines or support for how to use the system had been almost non-existent. The implementation had according to many been performed without involving the crews. Some crew members also felt reluctant to use it because it was interpreted as a surveillance tool for the owner rather than a support for work.

It is difficult to change established work practices which have evolved over the years in order to deal with the traditional objectives, resources and tools (Engeström, 2005). In order to address contradictions in activity systems and develop new technology-mediated practices practitioners within the concerned activity systems need, according (Engeström, 2005), to, first, identify and acknowledge the tensions, and second, to engage in, what in activity theoretical terms, is known as collaborative expansive learning; questioning of the status quo; analysis of the contradictions;

proposal of solution; implementation of new practice and; reflection on the process leading to the new practice. Although the company managers had questioned the status quo of energy efficiency improvement they had not analyzed and did not seem explicitly conscious about the contradictions that existed before and that emerged after the introduction of the monitoring system, nor had they engaged the seafarers in resolving them and developing new analytical and collaborative practices. In order to take advantage of the potential of energy monitoring system in shipping new collaborative practices between ship and shore had to be developed.

Conclusions based on paper II:

The adoption of technologies and policies for improving energy efficiency can be limited if the activity systems, in which practitioners (e.g. seafarers or managers) work, and which define the logic, the objectives and the social order (community of practice, division of labor) of the activity, is misaligned or in contradiction with the objective of energy efficiency and the practices implicated by the system and policy. New technologies and policies ought therefore not only be add-ons to an existing structure of work but have to be made consistent with the activity system in which they are intended to be embedded.

Paper III

Viktorelius, M., 2019. Adoption and use of energy-monitoring technology in ship officers' communities of practice. *Cognition, Technology & Work*, 1-13.

Similar to the previous paper II, the second case study reported in this publication also focused on the implementation adoption and use of an energy performance monitoring and analysis system on board passenger ferries. As opposed to the previous shipping company studied in papers I, II and IV, the company investigated in paper III had fared better in implementing their energy monitoring system onboard their vessels and had succeeded in saving substantial amounts of fuel through improved maneuvering and navigational practices. The study reported in paper III therefore constitutes a valuable comparative case to be contrasted and analyzed against the first study. The findings illustrate, drawing on the theory of communities of practice (Wenger, 1998), how the initial rejection and dis-use of the system among the navigating officers changed once they got the opportunity to re-negotiate the system as a collaborative technology-in-practice and started to collectively explore the possibilities of the system in operation.

The meaning of the newly installed energy performance monitoring system was, as in case study I, initially interpreted by the officers as a control tool diminishing their power, authority and autonomy. This posed a perceived threat to their professional identity as both competent and self-sufficient practitioners. The internally defined joint enterprise (what is seen as required for work) and the established repertoire of tools seen to be needed onboard the ships created a barrier of implementing the new system and seemed to require an expansion of the community's conception of itself and its practices (as improvable). The traditional boundary between the ship and shore community did not allow a straightforward implementation and adoption of the system in the work practices onboard. In particular, the initial efforts of implementation failed, according to the managers, because, admittedly, it was not sufficiently based in the social dynamic of the community of officers. To reframe the use of the system, as a tool assisting in work, and as a new domain of competence, it had to be re-enacted from within the onboard community of practice as a legitimate element in the officers' joint enterprise and shared repertoire.

Management thus created an opportunity for officers to engage in a process of peer-to-peer learning where the meaning of the system and the potential improvement in maneuvering and navigational practices could be explored. The idea to gather a small test group of officers and give them the authority to define the problem and play with the system was a first important step towards such a process. The group quickly felt ownership and interest in exploring the system and the possibilities for improvement. Here it can be noted that while the company in study II also instructed its crew members to use their system "in whatever way they wanted" the managers in case study I did not encourage or help them organize any opportunities for work-place learning as in study II. The experience and knowledge created in the test group described in study II (paper III) was later utilized in the subsequent approach of the rest of the crew. The dissemination of the new technology-in-practice (this time as interpreted and appropriated by practitioners from inside the community) required further negotiations and interactions between officers. The subsequent peer-training sessions functioned as a socially legitimate arena in which colleague officers could explore the system together and evaluate possible changes in their ship handling habits. Here, the test group, and in particular two peer-training moderators (colleague navigating officers), played an important role in legitimizing the system in the community. The use of the fuel monitoring technology became legitimate (considered as a candidate for inclusion in the shared repertoire) first when practitioners with full memberships in the community of practice (navigating officers) started to engage other colleagues and initiated a mutual negotiation about the system. The moderators' role as boundary spanners (Levina and Vaast, 2005) crossing the boundary between the ship and shore community, made it possible for other officers to perceive the introduction of the system as 'in their hands' and become open for to new experiences, thus expanding the current regime of competence in the community. When officers began to realize that other colleagues were saving energy, their felt need to keep up with the rest of the community motivated them to improve the energy efficiency of their work.

Conclusions based on paper III:

The findings in this study suggests that the adoption of new technologies depends on practitioners' autonomy and power to define and negotiate the meaning and role of new technologies in their community of practice. Seafarers belong to a profession historically characterized by its self-sufficiency, strong identity, pride, hierarchical power structure, discretion and internally enacted norms of competence. This is likely to contribute, as demonstrated in this study, to resistance to measures (new technologies or policies) introduced by people (mangers) outside the community. Hence, for new technologies, such as energy-monitoring systems, to become successfully adopted by seafarers and integrated in practice, the artefact has to be enacted as a legitimate and meaningful element in the joint enterprise and shared repertoire. An important conclusion is that change cannot not solely be facilitated by the information offered by new systems but crucially depended on how the system is collectively enacted in practice and the situated learning that take place among practitioners in relation to the possibilities of the system and the potential improvements in their work routines.

Paper IV

Viktorelius, M., MacKinnon, S. N., Lundh, M. (20XX) Energy efficiency, automation and the imbrication of human and material agency onboard passenger ferries. Submitted to *Journal of human computer interaction studies* (under final review)

The last paper is situated in the debate on human automation interaction in general and in shipping in particular in order to shed light on the long-term development and appropriation of automated technologies supporting energy efficiency. Reviewing the generic literature on human automation interaction and maritime human factors it became clear that current theories and empirical studies have not focused on how automated technologies are integrated in work practice over time. Moreover, most maritime studies interested in automation have focused on implications for safety, rather than energy efficiency, and investigated cognitive predictors of human performance in experimental settings, rather than adoption and appropriation in naturalistic field studies. A gap in the literature was thus identified. Building on Leonardi's theory of imbrication (2011) this study investigated how the relation between technologies, social context and work practice transform and influence each other over time.

While the previous two studies focused on the implementation of new monitoring technologies and the social process immediately after the introduction, this study took a longer time perspective by investigating a system that had been installed onboard the ships for a longer time. This allowed investigating the long-term processes and effects of introducing a technology and study its effects on practices and skills over time.

The paper describes the story of a dynamic speed auto-pilot supporting energy efficiency on two ships and illustrates how the appropriation process differed in the two settings, resulting in the development of different work practices, skills and social consequences. It was illustrated how the designed functionality of the technology, intended to automate part of the decision making during navigation (speed regulation), was not fully adopted by the crews on the grounds that the system could not make adequate situated judgements and did not have the deep local and embodied knowledge about the ship and its route that the crew saw as necessary for both safe and energy efficient operation. Although the technology offered a seemingly reduced workload during navigation officers preferred to control the speed semi-manually and retain their human agency. However, rather than rejecting the entire system, the crew had engaged in a process of adapting and appropriating the technology to their practices in order to align the use of the speed-pilot with their professional knowledge and technical understanding. Moreover, as seen in the analysis, the appropriation of the technology took various forms on the two ships. While the perceived constraints of the system lead to the redesign of the system, and the subsequent development of a certain new type of skill and practice on one of the ships, the crew on the other ship interpreted the constraints in the system differently and developed a different set of skills and practice. The difference in the social and organizational consequences of the automated speed regulation system was thus mediated by how the crews on the respective ships interpreted and perceived the systems' affordances and constraints. A key factor in this difference was associated with social interactional patterns on the ships. In particular, the engine department had been more involved in influencing the deck (bridge) department in how the technology could be used on one of the ships. Here, the chief engineers' knowledge and interest in energy efficient propulsion had played a larger role and contributed to the development of a more radical change than on the second ship, on which the bridge crew had developed a practice of just monitoring and overruling the technology rather than rebuilding it and using it in a novel way as on the ship with a stronger engine department influence. In addition, while the rejection and subsequent redesign of the system on the first ship had brought the bridge and engine departments together, this was not the case on the second ship which had developed tensions between the deck and engine departments due to the use of the system. Hence, the material agency of the technology and the human agency of the crews were differently entangled with each other, shaping each other over time, and evolving along different paths leading up the two quite different sets of skills and practices of speed regulation intended to be energy efficient.

Conclusions based on paper IV:

The study shows that the appropriation of technologies (in this case, technologies automating speed regulation for improved energy efficiency) does not end after its initial adoption but can continue to transform work, practices and skills several years after its installation. It was also illustrated how relatively similar work settings (in terms of crew training, operational and technical conditions) can involve different appropriations of the same technologies, and hence different effects and consequences, as a result of the social context (interactional patterns). One implication for the improvement of energy efficiency, suggested by the results, is that the management of technological practices require continuous attention even after initial implementation and training. While previous research tends to assume that technological measures have stable and predictable effects on work practices, this study has showed that even technologies involving automation involve temporally extended appropriations and require life-long management and learning.

6 Discussion

The aim of this thesis was to gain a deeper understanding about ship energy efficiency as a situated sociomaterial phenomenon by investigating the energy saving practices of crew members and the adoption of technologies supporting energy efficient ship operation. The research questions were formulated as:

- What are the challenges of realizing operational energy efficiency as seen from the perspective of seafarers' work and everyday activities onboard ships?

- How are technologies supporting operational energy efficiency adopted onboard ships?

- How do skills, practices and work onboard ships change as a result of the introduction of technologies and policies supporting operational energy efficiency?

There are many challenges associated with improving energy efficiency, and even more to actually reduce total emissions from shipping (Bazari and Longva, 2011). Thollander et al. (2019, 9) describe energy efficiency as a wicked interdisciplinary problem and emphasize that it is not merely the installation of technical mitigation measures that makes it recalcitrant but "actors' ways of discussing and understanding it" and "the actual decision-making process and the level of needed knowledge involved in decision-making that give rise to the wickedness". There are indeed, as expressed by Johnson (2016) "an overwhelming number of stories to be told, to relate to, to tell, before one can say with reasonable confidence what to do when it comes to research on energy efficiency in shipping". This means that any scientific account of the challenges and possible solutions connected to energy efficiency will necessarily only be partial and non-exhaustive. This has, however, more to do with the complex nature of improving energy efficiency as an organizational process, than with methodological limitations.

It has been argued in this thesis that the heterogeneity of energy efficiency requires an ethnographic approach to study the interplay and mutual entanglement of human, cultural and technological features constituting energy practices (Lutzenhiser, 2014; Palm and Thollander, 2020; Shove, 1998). Following Latour (2005), Johnson and Styhre (2015) suggested that "barriers" and "drivers" in energy research do not explain much but have to be explained instead:

Rather than ostensive explanations (postulated mechanisms or principles, such as "barriers" or "drivers"), there is a need for explanations that are performative (Latour, 1986; Czarniawska, 2008): i.e., a focus on capturing practices rather than formulating principles. How are people in an organization hindered from or driven to implement measures that increase energy efficiency?

Adhering to this recommendation, this thesis has investigated seafarers' adoption of technologies and practices and developed the sociomaterial practice-based perspective on energy efficiency in shipping (Gherardi, 2012; Nicolini, 2012). Looking at operational energy efficiency as a practical achievement through the prism of crew members' work revealed a lot of the sociomaterial complexity associated with energy optimization. The energy efficiency work onboard was shown to take place in particular social, material and institutional contexts which shaped how the work was performed. It was shown how the adoption of technologies and practices, supposed to support fuel savings, were dependent on crew members' knowing, learning, meanings, negotiations and interpretations in their communities of practice (Orlikowski, 1992; Wenger, 1998) and the division of labor, existing rules and tools in their activity systems (Engeström, 2000).

This chapter aims at answering the research questions by summarizing the threads in the different papers and by discussing the findings in light of previous research. It gives a unifying conceptual picture of (a) the work and challenges associated with energy efficiency, (b) the adoption of technologies and practices related to energy efficiency and (c) the ways in which technologies and policies, supporting energy efficiency, can come to play a role in the development of work and practices. Figure. 5. gives an overview of the research questions addressed by the different papers. The following table 2 is a summary of the answers further elaborated below.

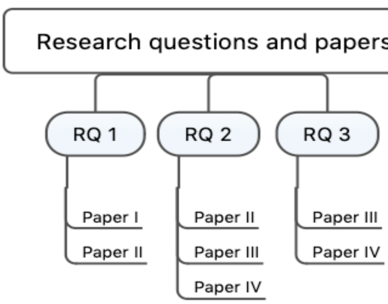

Fig. 5 Overview of the links between research questions and papers.

Table 2 Q&A

What are the challenges of realizing operational energy efficiency as seen from the perspective of seafarers' work and everyday activities onboard ships?	***How are technologies supporting operational energy efficiency adopted onboard ships?***	***How do skills, practices and work onboard ships change as a result of the introduction technologies supporting operational energy efficiency?***
Complexity of the factors influencing fuel consumption as well as difficulties in understanding and predicting the effect of different actions and decisions on energy efficiency	The adoption of technologies supporting operational energy efficiency is an inherently social and collective process	Technologies and policies do not determine how skills and practices change.
Conceptual elusiveness of the measurement of energy efficiency grounded in differing roles and responsibilities onboard	Adoption can be understood as a process of appropriation through which technologies (e.g. for monitoring and analyzing energy consumption) are rendered meaningful by seafarers' in their communities of practice	The effect depends on how technologies and policies are appropriated and enacted and on the details of how human and material agency is imbricated over time
The need to adapt and situate known measures for improving energy efficiency to local conditions (lack of straightforward transferability of knowledge)	Appropriation requires social interaction, negotiation of meaning and situated learning among seafarers (but is not guaranteed by it)	
Experienced based energy saving practices with insufficient grounding in data (need for energy monitoring and evaluation practices)	Over time, prolonged appropriations can lead to the enactment of particular technologies-in-practice (taken for granted and institutionalized tools used in everyday work)	
Contradictory demands and objectives competing with energy efficiency	The adoption of technology can vary as a result of practitioners' interpretations, managerial practices (implementation strategies) and institutional conditions defining a work setting: • Technologies are likely to be rejected if undermining the norms, socially defined competencies in seafarers' communities of practice • The introduction of technologies can lead to contradictions in the activity systems of seafarers (e.g. tensions between rules, tool, objectives) which need to be addressed in order for adoption to take place • Successful implementation of technologies (adoption) requires a participatory and engaging approach for encouraging crew members to learn and use the system	

RQ 1: The complexity and contradictions of saving energy as sea

Ships are complex energy systems and voyages take place in unpredictable and changing environments with constantly changing conditions influencing energy consumption; elements of the system interact in complex and non-linear ways with each other and with the outer environmental and operational conditions, making the effects of operational decisions difficult to predict (Baldi, 2016; Yan et al., 2018). The complexity of ship energy efficiency was seen to pose several difficulties for the seafarers in both case studies (I and II).

First, energy efficiency was perceived by most seafarers to be an elusive concept, making its realization difficult to conceptualize. A high fuel consumption was, for instance, not necessarily seen as low in energy efficiency, if the whole voyage, including the weather and traffic maneuvers, at that particular day, was also taken into account. Several different real-time measures or indicators of energy efficiency were available on the ships, such as the fuel consumption per nautical mile, per hour or per unit of power output. However, no unified technical definition of energy efficiency was used onboard the ships since most crew members thought that they all made invisible the situated causes of the fluctuating energy consumption. Without an understanding of the causes of a particular level of energy efficiency there was no value, according to the seafarers, of an indicator. Moreover, there was a difference in which indicator crew members thought best captured their conception of energy efficiency, if they had to choose one. The differing conceptions of energy efficiency were partly grounded in the different work practices engaged in by the two categories of crew members (deck and engine officer). While bridge officers and masters often preferred to think in terms of liters per nautical miles, regardless of how many engines were used, engineers were more interested in liters per hour or per unit of power output on each individual engine used, as an indicator of fuel efficiency. Since a low consumption per distance did not always correspond to the efficiency of individual engines, crew members were not always able to share a common understanding of the level of efficiency of the operation.

Second, the opportunities to save fuel were thought to be highly dependent on the particular ships and routes operated as well as the typical type and amount of cargo and time schedule. A short route with few changes in water depth and currents offered more possibilities than longer routes with varying water depth and currents. Crews on ships that were required to operate at maximum speed in order to meet the time schedule could not adapt the speed to varying environmental conditions in order to avoid peaks in fuel consumption. Crews on ships that were often fully booked had a harder time trying to depart early or plan the cargo placement more meticulously to save fuel. Previous research and debate on operational energy efficiency and the efficiency paradox in shipping often treat known measures for improving energy efficiency as generalizable and transferable solutions, or best practices, applicable in most settings (Bännstrand et al., 2016; Bouman et al., 2017). The findings in this thesis suggests, however, that the application of measures such as "optimized voyage execution" requires a situated adaptation where the crew have to identify how to optimize the energy consumption given the unique conditions defining their work context (ship design, operational assignment, etc.). While the goal in implementing available measures of operational energy efficiency might be the same across contexts, it is unlikely to involve the exact same organizational change process. Instead, optimization was seen to require considerable local knowledge which the seafarers had to acquire through contextual learning and experience (paper I, III and IV). The findings therefore nuance the traditional picture, also known as the diffusion model (Shove, 1998), often encountered in energy research and debate, where the potential for energy efficiency is seen to consist in readily transferable measures thought to be identified by researchers or experts in the field, and then spread in a sector through a linearly sequential process. Instead the potential for energy efficiency in shipping should rather be conceived as residing in particular and partly unique sociotechnical settings and situations to be identified by the practitioners, managers and operators working in those contexts.

Third, the findings showed that while officers, masters and engineers were making constant judgements on the effect of various factors, such as wind, currents, water depth, speed and route on the consumption of fuel, they had few methods to weigh them against each other or determine their actual relation in any systematic manner. The energy saving practices had developed over the years through sporadic discussions and personal experiences, sometimes based on what was considered common sense but rarely with the help of actual measurements and comparisons. Crew members did mention investigations, performed by interested colleagues, that had been made in the past comparing various operational options for saving energy but that were never documented and only traded to other colleagues verbally. Masters collected statistics on fuel consumption but most often kept the numbers on their office computer and treated them as administrative requirements associated with their duties as commander of the ship, rather than operational tools for the whole crew. The crews had experience of having sent in reports on the consumption from the previous day or week and other parameters related to energy efficiency as long as they could remember without getting any or very little feedback, guidance or instruction from shore management on how to improve their practices. This was a source of frustration and contributed to a feeling of futility regarding the reports.

One major challenge in improving operational energy efficiency in both case studies was therefore associated with the lack of a more systematic and data-based approach to the evaluation of current operational practices and more organized ways of sharing knowledge and experience of previous evaluations. This confirms the findings of several previous studies (Borg and von Knorring, 2019; Borg and Yström, 2019; Hansen et al., 2020; Johnson and Andersson, 2014; Johnson et al., 2014; Johnson and Styhre, 2015; Kitada and Ölçer, 2015; Poulsen and Johnson, 2016; Poulsen and Sornn-Friese, 2015; Rasmussen et al., 2018). One consequence of this deficit was that few unambiguous or uncontested convictions related to energy efficiency were held collectively among the crew members. Instead, most actions known to influence fuel consumption were associated with either uncertainty or strong disagreement. In case study I, many experienced a frustration due to the uncertainty, complexity and lack of consensus regarding the proportional impact of the various factors and practices influencing energy efficiency. Some younger officers thought that senior officers had formed opinions on the topic without strong empirical basis and were not prone to update or revise their beliefs. Some of the most contested topics related to energy consumption included areas such as ship trim (what the most energy efficient ship trim was on each particular voyage given the loading conditions) and propulsion (the most energy efficient use and load of main and auxiliary engine, speed, propeller pitch and RPM). There was therefore a clear need to develop both practices and tools onboard. This made the installation of the new energy monitoring system a justified move, in principle. However, as indicated by the findings, this was not sufficient for resolving the complexity in understanding energy efficiency and how to change practices (paper II and III).

Fourth, while the traditional practices and skills onboard the ships were mostly concerned with what was directly perceivable (e.g. ships on a radar, the sounding of an alarm, etc.) and proximate in time and space (e.g. the next maneuver, the checking of a system, etc.), knowing and action related to energy efficiency required a radically different mindset and approach. Essentially, it was thought to involve a shift in perspective from the immediate effect of the next action to the complex relationship between 'factors' influencing energy consumption, visible only through an abstract lens offered by accumulated data. This involved a transition that was not easily integrated with the perceived traditional demands of navigation. Many seafarers expressed an attitude of energy efficiency being a "academic" concern and that ship operation was all about "here and now".

Finally, a further challenge was related to the existence of various competing demands and objectives shaping the seafarers' work, confirming the studies of Hansen et al. (2020) and Rasmussen et al. (2018). While energy efficiency did feature as an explicit target introduced by shore management in both case studies, crews were not expected to compromise with safety or the quality of the transportation service they were providing. The objectives of safety and efficiency were often seen to stand in partial opposition to each other. Locally developed norms and practices (e.g. of where or when to start and stop extra engines for maneuvering) and the masters' subjective feeling of having control and being safe, played an important part in determining where to draw the line between safety and energy efficiency. In case study I, most maintained that the fuel consumption reduced with a forward ship trim but many masters and navigators claimed that this unfortunately also reduced the maneuverability of the ship since the propellers came nearer the water surface. Another issue, related to both the tradeoff between safety and energy efficiency as well as the tradeoff between energy efficiency and punctuality, was how many engines to run in order to avoid black outs and be on time. This was always a situated judgment based on the current weather and traffic conditions and embodied knowledge about the capacity of the ship. Moreover, while keeping a low average ship speed was known to be of essence for energy efficiency, it was often in conflict with the ambition of waiting for more passengers before departure or increasing speed in order to be on scheduled time in cases of delay. Judgments of the relation between safety, profitability and energy efficiency differed between ships and contexts and between departments, or rather, the communities of practice constituting them. For instance, engineers in the engine department, who lacked the navigational knowledge and embodied sense of ship handling, were generally critical of masters demanding, what they perceived as, too many engines. What was seen as a safety margin on the bridge was sometimes seen as inefficiency in the operation of the engines in the engine department. Masters, on the other hand, cared less about the fuel efficiency of individual machinery and more about consequences of not being able to control the ship in all circumstances.

In summary, the difficulties and challenges related to the realization of energy efficiency as seen from the perspective of everyday work described in this thesis ranged over a heterogenous, although interconnected, array of sociomaterial reasons including the elusiveness of energy efficiency, the context-dependedness of measures, uncertainty, complexity and lack of consensus regarding optimal actions, departmental disagreements, difficulties of integrating analysis with ordinary work, and finally, competition with other objectives. This does not mean that the crews had no motivation or were not engaged in trying to save as much fuel as they could. They saw it as their professional duty not to waste fuel and were aware about economic and environmental benefits of reduced energy consumption. Many did see it as a vocational challenge to compete with themselves and other ships and often compared the total fuel consumption of a completed voyage with that of previous voyages. Low fuel consumption was associated with a sense of pride and those navigators considered most competent by other officers, masters and engineers were often described as fuel conservative in their maneuvers and use of engine power. However, as expected given the practice-based theoretical approach (Gherardi, 2012) taken in this thesis, the challenges of achieving energy efficiency turned out to be more complex than suggested by the traditional metaphors of the barrier model, implying the existence of easily removable external obstacles. In particular, the challenge, as seen from the perspective of the onboard work of seafarers, was seen to be grounded in the very practices constituting contemporary ship operation.

RQ 2: Adoption of tools supporting energy efficient ship operations: a process of appropriation & enactment

Some of the most important measures for improving energy efficiency in shipping depends, as descried in the introduction and literature review, on the adoption of technologies and practices by shipping companies. The adoption of energy efficiency measures depends, in the first line of decisions, on the efforts, strategies and business models of shipping companies, which are influenced by regulations, market conditions and local organizing capabilities and practices (Poulsen and Johnson, 2016; Poulsen and Sornn-Friese, 2015; von Knorring, 2019). The next step in the process requires implementing the technologies and practices onboard ships and hence necessarily involves the crew. This thesis focused on the second step of technology adoption since it had not been sufficiently explored and investigated in previous research.

In the diffusion and barrier models described in chapter 2, technology adoption is primarily seen as depending on the transfer of knowledge from outside experts and researchers while adoption failures are seen as symptoms of insufficient information, awareness or knowledge about the benefits and objective scientific rationality of existing technologies. In contrast to this, the thesis has argued and showed that adoption is a locally configured process governed by the practical rationality or logic of a particular setting (Sandberg and Tsoukas, 2011). In particular, the findings showed that technologies supporting energy efficiency were differently adopted as a result of the meanings, affordances and constraints attributed to the technologies by actors involved in the implementation process as well as the context in which the technologies were introduced. The context should here not merely be understood as 'the maritime domain' or ships in general, but the locally developed and situated practices as enacted by particular individuals acting within particular systems of rules, tools, communities and divisions of labor.

Based on the findings in this thesis, technology adoption in workplaces can be understood as a two-step process involving appropriation and enactment. Appropriation involves rendering a technology a meaningful component of a practice. This was seen to be a situated and collective process of negotiation, interaction and communication among the seafarers. The sense of meaningfulness associated with a particular artefact was seen to depend on the seafarers' interpretation of it as a tool aligned and compatible with the locally configured social order and regime of competence. Appropriation was demonstrated to be a recursive process of locally adapting and finding ways of using the technology (including re-configuring the technology) and in changing work practices and self-understandings in order to align the technology with the modified work order. In paper III, officers recursively developed a way of using the monitoring system and modified their self-image and reflection on work in a way that was made to align with their general identity as competent professionals with ambitions to learn. This was also seen in paper IV where the seafarers selectively adapted and modified features of the automated speed system and changed their practices in a way that was made consistent with their interpretations, understandings and norms. Appropriation was seen to involve interpretative flexibility of technologies as indicated by the fact that functionally similar systems were perceived and treated differently on the different ships. While the crew members, followed in the first case study, considered their new energy monitoring system "a more or less meaningless thing" (Engineer, ship 4, paper II) the officers in the second case study gradually came to appreciate the role of their energy monitoring system as they engaged in the collaborative explorations of its use. Similarly, while the crew on one of the ships in paper IV rejected some fundamental features of the automated speed regulation system and abandoned the intended use of the system, the crew members on the other ship thought that it could be used, as long as it was monitored.

While appropriation can be seen as the first logical step of technological adoption in a workplace, enactment is the result of a longer and more stable pattern of appropriation leading to the institutionalization of a particular technology-in-practice whereby the technology and its use is taken for granted and stabilized (for now). This was illustrated in paper IV where the different ways of using the automated speed system on the two ships analyzed, was no longer questioned but had become "the ways things are done here". However, in neither of the two case studies was the energy monitoring systems properly enacted (it did not become an institutionalized element of their recurrent practice). While the officers in the second study did appropriate the technology during the peer-training sessions which lead to improvements in energy efficiency and the development of their skills, it did not fully reach a level where monitoring and evaluation became an everyday taken for granted aspect of their practice. It only "existed" in and through the situated learning and interactions in the temporary peer-training session but not yet as part of the institutional order.

Moreover, technological adoption was found to be influenced not only by the local context of meaning and interactions but also by the broader activity system in which seafarers worked as well as by the managerial implementation strategies pursued in the two shipping companies. The seafarers' rejection of the energy monitoring system in the first case study was, for instance, partly grounded in the lack of resources and support in the data analysis/evaluation work imposed by the system and the demands on productivity and high workload put on the them by the company. These features of the seafarers' activity system were difficult to align with the extra work (not fully appreciated by the managers) implicated by the intended use of the monitoring system. This was further exacerbated by the fact that the company in the first case study opted for an implementation strategy that merely involved the technical installation and a general information campaign including a workshop with introductory guidelines for the functionality of the energy monitoring system. This gave rise, however, to the suspicion by the crew members that the system had been installed in order to control the crew rather than support them.

The implementation strategy in the first company (case study I) was therefore an example of the most common way of onboard technology implementation in the shipping industry, as identified by previous research, showing that new technologies are seldom implemented by engaging the crew in the process or by offering adequate training for using the new tools (Bhardwaj et al., 2019; Sampson and Tang, 2015). Moreover, the implementation strategy used in the first company also manifested a Taylorist management philosophy, described in the literature as being counterproductive in the sense that more control and rules, and less support and seamanship, can generate resistance and rejection to adopt technologies (Knudsen, 2009).

While initially having the same implementation strategy as in the first company, the manager responsible for the energy saving project in study II changed her approach when noticing a resistance from the crews. The second company chose a more participatory and engaging approach for encouraging crew members to use the system. The difference in strategy was partly explained by the fact that the company in the first case study was one of the world's largest ferry operators with 37 vessels and 20 routes in Scandinavia, Great Britten and the Baltics, and thus had to find an efficient and practically feasible way of introducing the system onboard its ships. The company in the second case study was a much smaller company where the management knew all crew members personally and could thus maintain a closer collaboration during the implementation process. Nevertheless, the results speak its own language and illustrates how the social distance between shore and ships had an influence on the adoption of the respective systems. In particular, given the fact that the purpose of the system (in both case studies) was to make seafarers *learn* how to operate the ships in a more energy efficient manner, it was not successful to enforce or mandate the use of the technology. However, neither was it enough to have it running in the background or for officers to look passively at the screen displaying the fuel consumption in order for the system to fulfill its purpose. It had to be actively engaged with in motivated attempts to explore better ways of working. For this reason, the decision to allocate time and resources for a test group with officers and shore staff to first explore the possibilities of the technology and then to organize peer-training sessions where knowledge could be shared, proved to be a successful strategy (case study II).

In summary, due to the socially contingent nature of the appropriation and enactment processes, adoption is not a binary state and uniform process but will likely differ in degree between settings and over time. In particular, it was seen how the interpretative flexibility of very similar technologies lead to the enactment of various technologies-in-practice (Orlikowski, 1992, 2000). The findings suggest that non-adoption of technologies is not necessarily a matter of insufficient understanding or lack of knowledge regarding the technology but depends on the practical rationality, perceived meaning of the technology and the broader conditions of the activity systems in which technologies are embedded. Successful implementation and adoption of new technologies was seen to require work and active participation of the crew and a management strategy supporting the competence and professional identity of seafarers. It was shown how the adoption and appropriation of technologies required learning and the development of new skills and understandings of the seafarers' own work. This was seen to be contingent on the crew members' opportunity to engage in collaborative exploration of the technology and the ability to connect the mutually negotiated meaning of the system to the broader body of knowledge and practice characterizing ship operation, as defined in local communities of practice. In addition to illustrating the importance and engaging the crew in the implementation of new technologies onboard ships, the papers II-IV also demonstrate that technologies are not neutral devices but socially, culturally and emotionally laden artefacts. As such, they are not merely extensions of human cognitive processing, to be technically fitted, or adapted, to human limitations and capabilities, but tools mediating and enacting different collective activities, social practices, skills, identities and objectives.

RQ 3: The effects of new technologies and policies on the work and organizing of energy efficiency onboard ships

A lot of the mainstream research both on energy efficiency and technology in maritime work has assumed that new technologies and policies have certain predictable effects. As seen in the theoretical literature review, a majority of the studies in maritime human factors aim, for instance, at investigating and predicting the impact of certain technologies on either human or systems performance. It is acknowledged that this effect can be mediated by various cognitive factors such as workload and situation awareness and even by such recalcitrant phenomena as tacit knowledge or informal human relationships, but the consequences are thought to be determinable nevertheless. This thesis has shown that such stable and predictable (generalizable) effects are not likely to hold but are always situated and dependent on the social, material and cultural context, that is, on how technologies are adopted and enacted in practice. Claiming that if only people did what they are told the world would be more predictable, safe and efficient, is to misunderstand, or at least ignore, what is required for work to be done.

The findings in this thesis suggest that the impact or consequences of a technology is not directly caused by it but emerge as a result of the imbrication of social and material agency over time. The three technologies investigated in this thesis all had very different consequences for the work, skills and practices of the seafarers. Although the energy monitoring system investigated in paper II and III had a similar design and logic it gave rise to different outcomes in the two shipping companies (rejection, irritation, reduced trust between ship and shore vs. improved energy efficiency, the development of skills). In the first case study, the system had no observable or reported effects on the skills and practices of the seafarers. Instead of resolving uncertainties, the system merely highlighted the disagreements and re-actualized the contradictions inherent in the activity system. In the second case study, the crew members were able to appropriate the technology in a way that facilitated their understanding of their own practices and improved energy efficiency. This was however not a direct effect of the technology but the result of an extended social process of exploration, negotiation, interaction and learning. In order for the system to exert its representational functions (monitor fuel consumption) in a consequential way, the system had to first be made sense of, i.e. it had to be rendered a meaningful tool in the overall activity system and practice of the officers. The fourth paper (IV), further elaborated on the process of integration and transformation (imbrication) over time, illustrating how the enactment of a particular technology-in-practice may keep on changing with time as practitioners learn and develop their collective skills, goals, norms and beliefs. While two of the ships in paper IV had been equipped with the same technology, they eventually developed operationally different interpretations, practices and skills related to its use and strategies of energy saving, depending on the social interactional patterns onboard. Moreover, is was also seen how the different interpretative paths taken by the two ships resulted in further distinct social consequences for the relation and communication patterns between the bridge and the engine control room.

The impact of technology was thus seen to be contingent on (mediated by) the social process by which the technologies were translated into practice by humans (adopted, appropriated and enacted). The studies illustrate how the effect of introducing technologies into the workplace, such as the energy performance monitoring tool or the speed autopilot, was not solely determined by the technical features of the technologies but depended on the perceived meanings, affordances and constraints as well as the activities, practices, norms and know-how in the particular settings. Consequences were also dependent on the institutional context and the activity systems in which technologies were embedded.

Technological impact can thus be understood as a byproduct of how practitioners make sense of, appropriate and enact technologies in practice, which is a situated and improvisational process (in neither of the cases were the appropriations planned but emerged from the interactions between colleagues onboard each ship). In other words, it is suggested in this thesis that the process of technological impact is not merely a top-down one-way causal flow from technological functions or generic prescriptive formulations of work (as imagined) to human and systemic performance, but a recursive relationship between social agency and selected/adapted material features of technologies.

The findings and analyzed processes apply not only to the introduction and impact of technologies for improving energy efficiency but to policy and regulation as well. While all ships in the first case study had a required ship energy efficiency management plan (SEEMP) it did not seem to have any effect on the operational practices and everyday actions and decisions of the seafarers. This was not a surprising finding. Containing general statements about the process of ship energy management, a SEEMP says little about the actual situated actions required for the enactment of energy management. In an analysis of the SEEMP Guideline issued by IMO, Hansen et al. (2020, 2) argue that it is "an example of a goal-based regulation, where the authorities demand certain results without giving description of how to reach them, thus leaving room for interpretation". This is not necessarily a shortcoming of the guideline but a result of the format and logic of any general guideline or plan. The findings in this thesis therefore highlight the distinction between the ostensive (ideal, abstract, generalized idea and schematic form of the routine) and the performative aspect of routines (specific actions, by specific people, in specific places and times) emphasized by Feldman and Pentland (2003). Plans can never specify what is actually needed or what practical obstacles and challenges that will be encountered on the way but requires a kind of improvisation and attention to the local sociomaterial resources specific to particular contexts (Suchman, 2007). The problem related to energy efficiency knowing is not lack of training about the *existence* of technologies and policies but the *integration* of tools and objectives into practices. This means that no amount of information about the ostensive aspect of energy management can take away the need to handle the contradictions that necessarily ensue in all attempts of organizational change. It is therefore up to the actors in the individual companies and ships to translate and enact the ostensive aspect of regulations such as SEEMP to actual actions of planning, monitoring, implementation and self-evaluation. This is far from simply being a matter of rule compliance, which in the case of the SEEMP is met by the ostensive criteria (having a written plan), but requires organization and work (von Knorring, 2019).

7 Conclusions

The research gap addressed in this thesis consist in the scarcity of studies investigating onboard practices of energy saving and the integration (adoption, appropriation and enactment) of technologies supporting energy efficiency in real work settings. Motivated by a recent criticism of previous research on energy efficiency in industrial settings, including the maritime sector, separating technical potential from social practices, this thesis conceptualized and investigated seafarers' knowledge and work for energy efficiency as situated in the everyday sociomaterial practices onboard ships. This thesis contributes with a detailed empirical account of the practice-based logic of seafarers work and knowing related to energy efficiency and with an analysis of how technologies supporting decision making are adopted, appropriated and enacted onboard ships.

First, the thesis illustrates crew members' constant consideration and awareness of energy efficiency, how continuous judgements and decisions regarding energy consumption are being made during all phases of work (cargo operations, maneuvering and navigation). It characterized seafarers' knowledge required for the accomplishment of operational energy efficiency as a collective, collaborative and embodied knowing-in-action. However, it also illustrated differences in judgements of what is or is not energy efficient depending on position in the community of practice (deck vs. engine department). Moreover, it describes the contradictions and challenges involved in operational energy efficiency as a goal in the work of crew members. It shows that other important goals involved in the work often conflict with the seafarers' attention and effort to reduce fuel consumption. Moreover, it was shown that the purely experience-based and informal on-the-job learning was not sufficient to resolve many of the uncertainties and informational complexities related to energy optimization. This suggested a clear need for technological aids (decision support tools) contributing to the development and improvement of onboard work practices.

Second, the integration of technologies supporting energy efficiency was seen to be highly dependent on social interaction and collective learning among seafarers as well as the activity system in which technologies are introduced. It was shown how significantly different levels of adoption and ways of appropriation of similar technologies resulted from how crew members collaborated and interacted with each other and with shore managers. It was illustrated that the acceptance and use (integration) of new technologies was dependent on local negotiations of meaning (what role does the technology have in our professional practice as seafarers? Does it serve a purpose for how we accomplish our work), and learning (how can we utilize the technology's functions? What practices of use would work for our part?).

Questioning the notion of technological determinism, were certain designs have certain effects, the thesis showed how digital and automated technologies can have different consequences for the skills, practices and social interactions onboard depending on how human and material agency is imbricated over time. It was also shown that the activity systems (including existing rules, objectives, resources and divisions of labor) in which crew members work can constrain or even contradict the adoption of certain technologies. It should be noted that contradictions of this type cannot necessarily be resolved by better interface design since they are less a matter of human cognitive limitations and more about the structure and practice of work. Instead shipping companies should spend more attention and resources to collaboratively develop seafarers' knowledge and practice related to operational energy efficiency.

In conclusion, while technologies, general training, information and policies encouraging energy saving onboard ships can have an important symbolic value it is generally not enough to change practices. It is rather the translation of the technologies, measures and policies, into practical actions and incorporated into everyday practices, routines and skills of seafarers and managers that can make a difference. This, however, seems to require more work and collaboration than is usually assumed to be required.

References

Allen, P., 2009. Perceptions of technology at sea amongst British seafaring officers. Ergonomics 52, 1206-1214.

Anderson, R.J., 1994. Representations and Requirements: The Value of Ethnography in System Design. Human–Computer Interaction 9, 151-182.

Armstrong, V.N., Banks, C., 2015. Integrated approach to vessel energy efficiency. Ocean Engineering 110, 39-48.

Baldauf, M., Benedict, K., Kirchhoff, M., Schaub, M., Gluch, M., Fischer, S., 2018a. Energy-Efficient Ship Operation: The Concept of Green Manoeuvring, Corporate Social Responsibility in the Maritime Industry. Springer, pp. 185-218.

Baldauf, M., Mehdi, S.R.A., Schaub, M., Benedict, K., Milbradt, G., Finger, G., Fischer, S., 2018b. Simulation-Based Support to Minimize Emissions and Improve Energy Efficiency of Ship Operations, in: Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F. (Eds.), Trends and Challenges in Maritime Energy Management. Springer International Publishing, Cham, pp. 231-244.

Baldi, F., 2016. Modelling, analysis and optimisation of ship energy systems. Chalmers University of Technology.

Banks, C., Turan, O., Incecik, A., Lazakis, I., Lu, R., 2014. Seafarers' current awareness, knowledge, motivation and ideas towards low carbon–energy efficient operations. Journal of Shipping and Ocean Engineering 2014, 11-20.

Bännstrand, M., Karlsson, R., Jönsson, A., Johnson, H., 2016. Study on the optimization of energy consumption as part of implementation of a Ship Energy Efficiency Management Plan (SEEMP), International Maritime Organisation (IMO): London, UK.

Barley, S.R., 1986. Technology as an Occasion for Structuring - Evidence from Observations of Ct Scanners and the Social-Order of Radiology Departments. Administrative Science Quarterly 31, 78-108.

Bazari, Z., Longva, T., 2011. Assessment of IMO mandated energy efficiency measures for international shipping. International Maritime Organization 10.

Bertram, K.M., Saricks, C.L., Gregory, E.W., 1983. Developing a comprehensive programme for improving shipboard energy efficiency. Transportation Planning and Technology 8, 161-175.

Beşikçi, E.B., Arslan, O., Turan, O., Ölçer, A.I., 2016. An artificial neural network based decision support system for energy efficient ship operations. Computers & Operations Research 66, 393-401.

Bhardwaj, S., 2013. Technology, and the up-skilling or deskilling conundrum. WMU Journal of Maritime Affairs 12, 245-253.

Bhardwaj, S., Bhattacharya, S., Tang, L., Howell, K.E., 2019. Technology introduction on ships: The tension between safety and economic rationality. Safety Science 115, 329-338.

Bhattacharya, S., 2012. The effectiveness of the ISM Code: A qualitative enquiry. Marine Policy 36, 528-535.

Bisantz, A.M., Roth, E., Brickman, B., Gosbee, L.L., Hettinger, L., McKinney, J., 2003. Integrating cognitive analyses in a large-scale system design process. International Journal of Human-Computer Studies 58, 177-206.

Bjørkli, C.A., Øvergård, K.I., Røed, B.K., Hoff, T., 2006. Control situations in high-speed craft operation. Cognition, Technology & Work 9, 67-80.

Blomberg, D.J., Karasti, H., 2012. Ethnography: Positioning ethnography within participatory design, Routledge international handbook of participatory design. Routledge, pp. 106-136.

Blomberg, J., Karasti, H., 2013. Reflections on 25 Years of Ethnography in CSCW. Computer Supported Cooperative Work (CSCW) 22, 373-423.

Borg, J., von Knorring, H., 2019. Inter-organizational collaboration for energy efficiency in the maritime sector: the case of a database project. Energy Efficiency.

Borg, J., Yström, A., 2019. Collaborating for energy efficiency in Swedish shipping industry: interrelating practice and challenges. Environment, Development and Sustainability.

Boström, M., 2018. Breaking the ice: a work domain analysis of icebreaker operations. Cognition, Technology & Work 20, 443-456.

Boudreau, M.C., Robey, D., 2005. Enacting integrated information technology: A human agency perspective. Organization Science 16, 3-18.

Boulding, K.E., 1981. Evolutionary economics. Sage Publications, Inc.

Bouman, E.A., Lindstad, E., Rialland, A.I., Stromman, A.H., 2017. State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping - A review. Transportation Research Part D-Transport and Environment 52, 408-421.

Braun, V., Clarke, V., 2006. Using thematic analysis in psychology. Qualitative Research in Psychology 3, 77-101.

Brown, J.S., Duguid, P., 1991. Organizational Learning and Communities-of-Practice: Toward a Unified View of Working, Learning, and Innovation. Organization Science 2, 40-57.

Brunke, J.-C., Johansson, M., Thollander, P., 2014. Empirical investigation of barriers and drivers to the adoption of energy conservation measures, energy management practices and energy services in the Swedish iron and steel industry. Journal of Cleaner Production 84, 509-525.

Button, G., 2000. The ethnographic tradition and design. Design Studies 21, 319-332.

Button, G., Sharrock, W., 2009. Studies of Work and the Workplace in HCI: Concepts and Techniques. Synthesis Lectures on Human-Centered Informatics 2, 1-96.

Cecez-Kecmanovic, D., Galliers, R.D., Henfridsson, O., Newell, S., Vidgen, R., 2014. The sociomateriality of information systems: current status, future directions. Mis Quarterly 38, 809-830.

Chauvin, C., Clostermann, J.P., Hoc, J.-M., 2008. Situation Awareness and the Decision-Making Process in a Dynamic Situation: Avoiding Collisions at Sea. Journal of Cognitive Engineering and Decision Making 2, 1-23.

Chauvin, C., Lardjane, S., 2008. Decision making and strategies in an interaction situation: Collision avoidance at sea. Transportation Research Part F: Traffic Psychology and Behaviour 11, 259-269.

Chi, H., Pedrielli, G., Ng, S.H., Kister, T., Bressan, S., 2018. A framework for real-time monitoring of energy efficiency of marine vessels. Energy 145, 246-260.

Cohen, I., Brinkman, W.-P., Neerincx, M.A., 2015. Modelling environmental and cognitive factors to predict performance in a stressful training scenario on a naval ship simulator. Cognition, Technology & Work 17, 503-519.

Cordon, J.R., Mestre, J.M., Walliser, J., 2017. Human factors in seafaring: The role of situation awareness. Safety Science 93, 256-265.

Corradi, G., Vendelø, M.T., Dehler, G.E., Christensen, P.H., Gherardi, S., Verzelloni, L., 2010. Through the practice lens: Where is the bandwagon of practice-based studies heading? Management Learning 41, 265-283.

Costa, N.A., Jakobsen, J.J., Weber, R., Lundh, M., MacKinnon, S.N., 2018. Assessing a maritime service website prototype in a ship bridge simulator: navigators' experiences

and perceptions of novel e-Navigation solutions. WMU Journal of Maritime Affairs 17, 521-542.
Costa, N.A., Lundh, M., MacKinnon, S.N., 2017. Non-technical communication factors at the Vessel Traffic Services. Cognition, Technology & Work 20, 63-72.
Crabtree, A., Nichols, D.M., O'Brien, J., Rouncefield, M., Twidale, M.B., 2000. Ethnomethodologically informed ethnography and information system design. Journal of the American Society for Information Science 51, 666-682.
Cummings, M.L., Buchin, M., Carrigan, G., Donmez, B., 2010. Supporting intelligent and trustworthy maritime path planning decisions. International Journal of Human-Computer Studies 68, 616-626.
Czarniawska, B., 2014. A theory of organizing. Edward Elgar Publishing.
de Vries, L., 2017. Work as Done? Understanding the Practice of Sociotechnical Work in the Maritime Domain. Journal of Cognitive Engineering and Decision Making 11, 270-295.
DeSanctis, G., Poole, M.S., 1994. Capturing the complexity in advanced technology use: Adaptive structuration theory. Organization science 5, 121-147.
Dewan, M.H., Yaakob, O., Suzana, A., 2018. Barriers for adoption of energy efficiency operational measures in shipping industry. WMU Journal of Maritime Affairs 17, 169-193.
Dhami, H., Grabowski, M., 2010. Technology impacts on safety and decision making over time in marine transportation. Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability 225, 269-292.
Dourish, P., 2003. The appropriation of interactive technologies: Some lessons from placeless documents. Computer Supported Cooperative Work (CSCW) 12, 465-490.
Dubois, A., Gadde, L.E., 2002. Systematic combining: an abductive approach to case research. Journal of Business Research 55, 553-560.
Dunlop, T., 2019. Mind the gap: A social sciences review of energy efficiency. Energy Research & Social Science 56.
Eldh, C., 2004. Den riskfyllda gemenskapen: att hantera säkerhet på ett passagerarfartyg. Arkiv förlag.
Engeström, Y., 1987. Learning by expanding. Cambridge University Press.
Engeström, Y., 2000. Activity theory as a framework for analyzing and redesigning work. Ergonomics 43, 960-974.
Engeström, Y., 2001. Expansive Learning at Work: Toward an activity theoretical reconceptualization. Journal of Education and Work 14, 133-156.
Engeström, Y., 2005. Developmental work research: Expanding activity theory in practice. Lehmanns Media.
Engeström, Y., Middleton, D., 1996. Cognition and communication at work. Cambridge University Press.
Feldman, M.S., Orlikowski, W.J., 2011. Theorizing Practice and Practicing Theory. Organization Science 22, 1240-1253.
Feldman, M.S., Pentland, B.T., 2003. Reconceptualizing organizational routines as a source of flexibility and change. Administrative science quarterly 48, 94-118.
Fenwick, T., Nerland, M., 2014. Reconceptualising professional learning: Sociomaterial knowledges, practices and responsibilities. Routledge.
Flick, U., 2000. Episodic interviewing. in M. Bauer and G. Gaskell (eds.), Qualitative Reseach with Text, Image and Sound: A Practical Handbook, 75-92.
Flick, U., 2014. The SAGE Handbook of Qualitative Data
Analysis.

Gherardi, S., 2008. Situated knowledge and situated action: What do practice-based studies promise. The SAGE handbook of new approaches in management and organization, 516-525.
Gherardi, S., 2010. Telemedicine: A practice-based approach to technology. Human Relations 63, 501-524.
Gherardi, S., 2012. How to conduct a practice-based study: Problems and methods. Edward Elgar Publishing.
Gould, K.S., Roed, B.K., Saus, E.R., Koefoed, V.F., Bridger, R.S., Moen, B.E., 2009. Effects of navigation method on workload and performance in simulated high-speed ship navigation. Appl Ergon 40, 103-114.
Grabowski, M., Wallace, W.A., 1993. An expert system for maritime pilots: Its design and assessment using gaming. Management science 39, 1506-1520.
Grootjen, M., Neerincx, M.A., Veltman, J.A., 2006. Cognitive task load in a naval ship control centre: from identification to prediction. Ergonomics 49, 1238-1264.
Grudin, J., 1988. Why CSCW applications fail: Problems in the design and evaluation of organizational interfaces. Microelectronics and Computer Technology Corporation.
Guy, S., Shove, E., 2000. The sociology of energy, buildings and the environment: Constructing knowledge, designing practice. Routledge
Hansen, E.K., Rasmussen, H.B., Lützen, M., 2020. Making shipping more carbon-friendly? Exploring ship energy efficiency management plans in legislation and practice. Energy Research & Social Science 65, 101459.
Harper, R.H.R., 2000. The organisation in ethnography–a discussion of ethnographic fieldwork programs in CSCW. Computer Supported Cooperative Work (CSCW) 9, 239-264.
Heath, C., Knoblauch, H., Luff, P., 2000. Technology and social interaction: the emergence of 'workplace studies'. British Journal of Sociology 51, 299-320.
Heath, C., Luff, P., 2000. Technology in action. Cambridge university press.
Herring, H., 2000. Is Energy Efficiency Environmentally Friendly? Energy & Environment 11, 313-325.
Herring, H., 2006. Energy efficiency—a critical view. Energy 31, 10-20.
Hockey, G., Healey, A., Crawshaw, M., Wastell, D.G., Sauer, J., 2003. Cognitive demands of collision avoidance in simulated ship control. Human factors 45, 252-265.
Horberry, T., Grech, M., Koester, T., 2008. Human factors in the maritime domain. CRC press.
Hutchins, E., 1995. Cognition in the Wild. MIT press.
Itoh, K., Yamaguchi, T., Hansen, J.P., Nielsen, F.R., 2001. Risk analysis of ship navigation by use of cognitive simulation. Cognition, Technology & Work 3, 4-21.
Jafarzadeh, S., Utne, I.B., 2014. A framework to bridge the energy efficiency gap in shipping. Energy 69, 603-612.
Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap What does it mean? Energy Policy 22, 804-810.
Jensen, S., Lützen, M., Mikkelsen, L.L., Rasmussen, H.B., Pedersen, P.V., Schamby, P., 2018. Energy-efficient operational training in a ship bridge simulator. Journal of Cleaner Production 171, 175-183.
Johnson, H., 2016. In search of maritime energy management. Chalmers University of Technology.
Johnson, H., Andersson, K., 2014. Barriers to energy efficiency in shipping. WMU Journal of Maritime Affairs 15, 79-96.

Johnson, H., Johansson, M., Andersson, K., 2014. Barriers to improving energy efficiency in short sea shipping: an action research case study. Journal of Cleaner Production 66, 317-327.
Johnson, H., Styhre, L., 2015. Increased energy efficiency in short sea shipping through decreased time in port. Transportation Research Part A: Policy and Practice 71, 167-178.
Kitada, M., Ölçer, A.I., 2015. Managing people and technology: The challenges in CSR and energy efficient shipping. Research in Transportation Business and Management 17, 36-40.
Knudsen, F., 2009. Paperwork at the service of safety? Workers' reluctance against written procedures exemplified by the concept of 'seamanship'. Safety Science 47, 295-303.
Latour, B., 1993. We have never been modern. Harvard university press.
Lave, J., 1988. Cognition in practice: Mind, mathematics and culture in everyday life. Cambridge University Press.
Lave, J., Wenger, E., 1991. Situated learning: Legitimate peripheral participation. Cambridge university press Cambridge.
Law, J., 1994. Organizing modernity. Blackwell Oxford.
Lee, J.D., Sanquist, T.F., 2000. Augmenting the operator function model with cognitive operations: Assessing the cognitive demands of technological innovation in ship navigation. IEEE Transactions on Systems, Man, and Cybernetics-Part A: Systems and Humans 30, 273-285.
Leonardi, P.M., 2009. Why Do People Reject New Technologies and Stymie Organizational Changes of Which They Are in Favor? Exploring Misalignments Between Social Interactions and Materiality. Human Communication Research 35, 407-441.
Leonardi, P.M., 2011. When Flexible Routines Meet Flexible Technologies: Affordance, Constraint, and the Imbrication of Human and Material Agencies. Mis Quarterly 35, 147-167.
Leonardi, P.M., 2013. Theoretical foundations for the study of sociomateriality. Information and Organization 23, 59-76.
Leonardi, P.M., Barley, S.R., 2010. What's under construction here? Social action, materiality, and power in constructivist studies of technology and organizing. The Academy of Management Annals 4, 1-51.
Levina, N., Vaast, E., 2005. The Emergence of Boundary Spanning Competence in Practice: Implications for Implementation and Use of Information Systems. MIS Quarterly 29, 335-363.
Ljung, M., Lützhöft, M., 2014. Functions, performances and perceptions of work on ships. WMU Journal of Maritime Affairs 13, 231-250.
Luff, P., Hindmarsh, J., Heath, C., 2000. Workplace studies: Recovering work practice and informing system design. Cambridge university press.
Lundh, M., Rydstedt, L.W., 2016. A static organization in a dynamic context--A qualitative study of changes in working conditions for Swedish engine officers. Appl Ergon 55, 1-7.
Lützen, M., Mikkelsen, L.L., Jensen, S., Rasmussen, H.B., 2017. Energy efficiency of working vessels – A framework. Journal of Cleaner Production 143, 90-99.
Lutzenhiser, L., 1994. Sociology, energy and interdisciplinary environmental science. The American Sociologist 25, 58-79.
Lutzenhiser, L., 2014. Through the energy efficiency looking glass. Energy Research & Social Science 1, 141-151.
Lützhöft, M., Nyce, J., 2008. Integration work on the ship's bridge. Journal of Maritime research 5, 59-74.

Mallam, S.C., Nazir, S., Sharma, A., 2019. The Human Element in Future Maritime Operations - Perceived Impact of Autonomous Shipping. Ergonomics, 1-29.
Man, Y., Lundh, M., MacKinnon, S., 2018a. Maritime Energy Efficiency in a Sociotechnical System: A Collaborative Learning Synergy via Mediating Technologies. TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation 12, 239-250.
Man, Y., Lützhöft, M., Costa, N.A., Lundh, M., MacKinnon, S.N., 2018b. Gaps Between Users and Designers: A Usability Study About a Tablet-Based Application Used on Ship Bridges, Advances in Human Aspects of Transportation, pp. 213-224.
Man, Y., Sturm, T., Lundh, M., MacKinnon, S.N., 2020. From Ethnographic Research to Big Data Analytics—A Case of Maritime Energy-Efficiency Optimization. Applied Sciences 10.
Man, Y., Weber, R., Cimbritz, J., Lundh, M., MacKinnon, S.N., 2018c. Human factor issues during remote ship monitoring tasks: An ecological lesson for system design in a distributed context. International Journal of Industrial Ergonomics 68, 231-244.
Miettinen, R., Samra-Fredericks, D., Yanow, D., 2009. Re-Turn to Practice: An Introductory Essay. 30, 1309-1327.
Moezzi, M., 2000. Decoupling energy efficiency from energy consumption. Energy & Environment 11, 521-537.
Nardi, B.A., 1996. Context and consciousness: activity theory and human-computer interaction. MIT Press.
Nardi, B.A., 1997. The use of ethnographic methods in design and evaluation, Handbook of human-computer interaction. Elsevier, pp. 361-366.
Nardi, B.A., Engeström, Y., 1999. A web on the wind: The structure of invisible work. Computer supported cooperative work 8, 1-8.
Nicolini, D., 2011. Practice as the Site of Knowing: Insights from the Field of Telemedicine. Organization Science 22, 602-620.
Nicolini, D., 2012. Practice theory, work, and organization: An introduction. OUP Oxford.
Nicolini, D., Gherardi, S., Yanow, D., 2003. Knowing in Organizations: A Practice-based Approach. ME Sharpe.
Nilsson, M., Laere, J.v., Susi, T., Ziemke, T., 2012. Information fusion in practice: A distributed cognition perspective on the active role of users. Information Fusion 13, 60-78.
Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F., 2018. Trends and Challenges in Maritime Energy Management. Springer.
Olsson, E., Jansson, A., 2007. Work on the bridge – studies of officers on high-speed ferries. Behaviour & Information Technology 25, 37-64.
Orlikowski, W.J., 1992. The Duality of Technology - Rethinking the Concept of Technology in Organizations. Organization Science 3, 398-427.
Orlikowski, W.J., 2000. Using technology and constituting structures: A practice lens for studying technology in organizations. Organization Science 11, 404-428.
Orlikowski, W.J., 2002. Knowing in practice: Enacting a collective capability in distributed organizing. Organization science 13, 249-273.
Orlikowski, W.J., 2007. Sociomaterial Practices: Exploring Technology at Work. Organization Studies 28, 1435-1448.
Orlikowski, W.J., Scott, S.V., 2008. 10 Sociomateriality: Challenging the Separation of Technology, Work and Organization. The Academy of Management Annals 2, 433-474.
Orr, J.E., 1996. Talking about machines: An ethnography of a modern job. Cornell University Press.

Øvergård, K.I., Bjørkli, C.A., Røed, B.K., Hoff, T., 2009. Control strategies used by experienced marine navigators: observation of verbal conversations during navigation training. Cognition, Technology & Work 12, 163-179.

Øvergård, K.I., Sorensen, L.J., Nazir, S., Martinsen, T.J., 2015. Critical incidents during dynamic positioning: operators' situation awareness and decision-making in maritime operations. Theoretical Issues in Ergonomics Science 16, 366-387.

Palm, J., Reindl, K., 2016. Understanding energy efficiency in Swedish residential building renovation: A practice theory approach. Energy Research & Social Science 11, 247-255.

Palm, J., Thollander, P., 2010. An interdisciplinary perspective on industrial energy efficiency. Applied Energy 87, 3255-3261.

Palm, J., Thollander, P., 2020. Reframing energy efficiency in industry: A discussion of definitions, rationales, and management practices, Energy and Behaviour, pp. 153-175.

Pan, Y., Hildre, H.P., 2018. Holistic human safety in the design of marine operations safety. Ocean Engineering 151, 378-389.

Patriarca, R., Bergström, J., 2017. Modelling complexity in everyday operations: functional resonance in maritime mooring at quay. Cognition, Technology & Work 19, 711-729.

Patterson, M.G., 1996. What is energy efficiency?: Concepts, indicators and methodological issues. Energy Policy 24, 377-390.

Pazouki, K., Forbes, N., Norman, R.A., Woodward, M.D., 2018. Investigation on the impact of human-automation interaction in maritime operations. Ocean Engineering 153, 297-304.

Pérez-Lombard, L., Ortiz, J., Velázquez, D., 2012. Revisiting energy efficiency fundamentals. Energy Efficiency 6, 239-254.

Petersen, J., 2004. Control situations in supervisory control. Cognition, Technology & Work 6, 266-274.

Plowman, L., Rogers, Y., Ramage, M., 1995. What are workplace studies for?, Proceedings of the Fourth European Conference on Computer-Supported Cooperative Work ECSCW'95. Springer, pp. 309-324.

Poulsen, R.T., Johnson, H., 2016. The logic of business vs. the logic of energy management practice: understanding the choices and effects of energy consumption monitoring systems in shipping companies. Journal of Cleaner Production 112, 3785-3797.

Poulsen, R.T., Sornn-Friese, H., 2015. Achieving energy efficient ship operations under third party management: How do ship management models influence energy efficiency? Research in Transportation Business & Management 17, 41-52.

Praetorius, G., Hollnagel, E., 2014. Control and Resilience Within the Maritime Traffic Management Domain. Journal of Cognitive Engineering and Decision Making 8, 303-317.

Praetorius, G., Hollnagel, E., Dahlman, J., 2015. Modelling Vessel Traffic Service to understand resilience in everyday operations. Reliability Engineering & System Safety 141, 10-21.

Randall, D., Harper, R., Rouncefield, M., 2007. Fieldwork for design: theory and practice. Springer Science & Business Media.

Rasmussen, H.B., Lutzen, M., Jensen, S., 2018. Energy efficiency at sea: Knowledge, communication, and situational awareness at offshore oil supply and wind turbine vessels. Energy Research & Social Science 44, 50-60.

Rehmatulla, N., Smith, T., 2015. Barriers to energy efficient and low carbon shipping. Ocean Engineering 110, 102-112.

Rivera, G., Cox, A., 2013. An evaluation of the practice based approach to understanding the adoption and use of information systems. Journal of Documentation 70, 878-901.
Rogers, Y., Marshall, P., 2017. Research in the Wild. Synthesis Lectures on Human-Centered Informatics 10, i-97.
Rony, A.H., Kitada, M., Dalaklis, D., Ölçer, A.I., Ballini, F., 2019. Exploring the new policy framework of environmental performance management for shipping: a pilot study. WMU Journal of Maritime Affairs 18, 1-24.
Ryle, G., 1949. The concept of mind. Pinguin
Sætrevik, B., Hystad, S.W., 2017. Situation awareness as a determinant for unsafe actions and subjective risk assessment on offshore attendant vessels. Safety Science 93, 214-221.
Sampson, H., Tang, L., 2015. Strange things happen at sea: training and new technology in a multi-billion global industry. Journal of Education and Work 29, 980-994.
Sampson, H., Turgo, N., Acejo, I., Ellis, N., Tang, L., 2019. 'Between a Rock and a Hard Place': The Implications of Lost Autonomy and Trust for Professionals at Sea. Work, Employment and Society 33, 648-665.
Sandberg, J., Dall'Alba, G., 2010. Returning to Practice Anew: A Life-World Perspective. Organization Studies 30, 1349-1368.
Sandberg, J., Tsoukas, H.J.A.o.m.r., 2011. Grasping the logic of practice: Theorizing through practical rationality. 36, 338-360.
Sandhaland, H., Oltedal, H.A., Hystad, S.W., Eid, J., 2015. Distributed situation awareness in complex collaborative systems: A field study of bridge operations on platform supply vessels. J Occup Organ Psychol 88, 273-294.
Schatzki, T.R., Knorr-Cetina, K., von Savigny, E., 2001. The Practice Turn in Contemporary Theory. Psychology Press.
Schøyen, H., Bråthen, S., 2015. Measuring and improving operational energy efficiency in short sea container shipping. Research in Transportation Business & Management 17, 26-35.
Schröder-Hinrichs, J.-U., Hollnagel, E., Baldauf, M., Hofmann, S., Kataria, A., 2013. Maritime human factors and IMO policy. Maritime Policy & Management 40, 243-260.
Schultze, U., Boland, R.J., 2000. Knowledge management technology and the reproduction of knowledge work practices. The Journal of Strategic Information Systems 9, 193-212.
Sellberg, C., 2016. Representing and enacting movement: The body as an instructional resource in a simulator-based environment. Education and Information Technologies 22, 2311-2332.
Sellberg, C., 2017a. From briefing, through scenario, to debriefing: the maritime instructor's work during simulator-based training. Cognition, Technology & Work 20, 49-62.
Sellberg, C., 2017b. Training to become a master mariner in a simulator-based environment: The instructors' contributions to professional learning. Gothenburg University
Sellberg, C., Lundin, M., 2017. Demonstrating professional intersubjectivity: The instructor's work in simulator-based learning environments. Learning, Culture and Social Interaction 13, 60-74.
Sellberg, C., Lundin, M., 2018. Tasks and instructions on the simulated bridge: Discourses of temporality in maritime training. Discourse Studies 20, 289-305.
Sharma, A., Nazir, S., Ernstsen, J., 2019. Situation awareness information requirements for maritime navigation: A goal directed task analysis. Safety Science 120, 745-752.
Sharrock, W., Hughes, J.A., 2001. Ethnography in the workplace: Remarks on its theoretical bases. Team Ethno 1.
Shove, E., 1998. Gaps, barriers and conceptual chasms: theories of technology transfer and energy in buildings. Energy Policy 26, 1105-1112.

Shove, E., 2017. What is wrong with energy efficiency? Building Research & Information 46, 779-789.
Shove, E., Walker, G., 2014. What Is Energy For? Social Practice and Energy Demand. 31, 41-58.
Silverman, D., 2014. Interpreting qualitative data. Sage.
Smith, T., Jalkanen, J., Anderson, B., Corbett, J., Faber, J., Hanayama, S., O'Keeffe, E., Parker, S., Johanasson, L., Aldous, L., 2014. Third IMO GHG Study 2014, International Maritime Organization (IMO), London, UK.
Sorrell, S., O'Malley, E., Schleich, J., Scott, S., 2004. The economics of energy efficiency: barriers to cost-effective investment. Edward Elgar Publishing, Cheltenham.
Sovacool, B.K., 2014. What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. Energy Research & Social Science 1, 1-29.
Suchman, L., 1995. Making work visible. Communications of the ACM 38, 56-ff.
Suchman, L., 2007. Human-machine reconfigurations: Plans and situated actions. Cambridge University Press.
Suchman, L., Blomberg, J., Orr, J.E., Trigg, R., 1999. Reconstructing technologies as social practice. American Behavioral Scientist 43, 392-408.
Szymanski, M.H., Whalen, J., 2011. Making work visible: Ethnographically grounded case studies of work practice. Cambridge University Press.
Tang, L., Sampson, H., 2017. Improving training outcomes: the significance of motivation when learning about new shipboard technology. Journal of Vocational Education & Training, 1-15.
Thollander, P., Palm, J., 2013. Improving energy efficiency in industrial energy systems: An interdisciplinary perspective on barriers, energy audits, energy management, policies, and programs. Springer Science & Business Media.
Thollander, P., Palm, J., Hedbrant, J., 2019. Energy Efficiency as a Wicked Problem. Sustainability 11.
Vaast, E., Walsham, G., 2005. Representations and actions: the transformation of work practices with IT use. Information and Organization 15, 65-89.
van Westrenen, F., 2010. Cognitive work analysis and the design of user interfaces. Cognition, Technology & Work 13, 31-42.
van Westrenen, F., Praetorius, G., 2012a. Maritime traffic management: a need for central coordination? Cognition, Technology & Work 16, 59-70.
van Westrenen, F., Praetorius, G., 2012b. Situation awareness and maritime traffic: having awareness or being in control? Theoretical Issues in Ergonomics Science 15, 161-180.
von Knorring, H., 2019. Energy audits in shipping companies. Transportation Research Part A: Policy and Practice 125, 35-55.
Wenger, E., 1998. Communities of practice: Learning, meaning, and identity. Cambridge university press.
Wu, Y., Miwa, T., Uchida, M., 2017. Using physiological signals to measure operator's mental workload in shipping – an engine room simulator study. Journal of Marine Engineering & Technology 16, 61-69.
Wulvik, A.S., Dybvik, H., Steinert, M., 2019. Investigating the relationship between mental state (workload and affect) and physiology in a control room setting (ship bridge simulator). Cognition, Technology & Work.
Yan, X., Wang, K., Yuan, Y., Jiang, X., Negenborn, R.R., 2018. Energy-efficient shipping: An application of big data analysis for optimizing engine speed of inland ships considering multiple environmental factors. Ocean Engineering 169, 457-468.

Zhang, S., Li, Y., Yuan, H., Sun, D., 2019. An alternative benchmarking tool for operational energy efficiency of ships and its policy implications. Journal of Cleaner Production 240, 118223.